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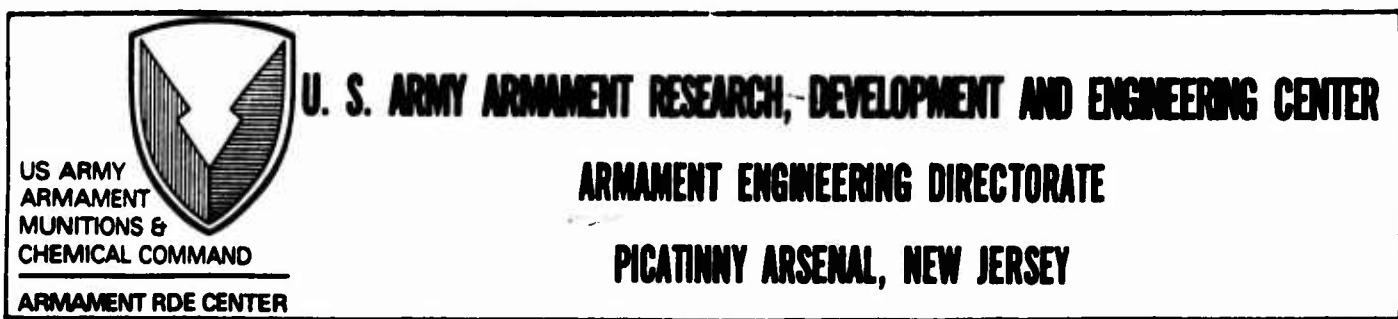
TECHNICAL REPORT ARAED-TR-87003

AUTOMATED M55 DETONATOR PRODUCTION EQUIPMENT, VOLUME I

PAUL P. MONTELEONE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The report describes and/or provides reference to publications relative to investigatory efforts into development of high rate (800 to 1200 parts per minute) M55 detonator assembly equipment and to development efforts for a modular M55 detonator assembly system with an assembly rate of some 150 to 200 parts per minute. Key words: M55, automation, technology,		

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INTRODUCTION

This report centers about improved methods of manufacture of one family of detonators (i.e., the nonelectric variety) where functioning is initiated by impact. More specifically, ~~this report~~ is directed toward modernized production of the ~~nonelectric~~ detonator with the highest usage factor (i.e., the M55 detonator). A diagram of the M55 detonator along with pertinent assembly data are shown in figure 1.

The M55 detonator can be produced on various pieces of equipment; however, the most frequently used equipment is the Jones loader and the Iowa loader. (figs. 2 and 3) These two pieces of equipment are each capable of producing the M55 detonator at a rate of approximately 35 to 40 detonators per minute. A station comparison of the two loaders is shown in table 1.

Based upon predicated mobilization requirements and guidelines, early modernization objectives were to design and develop a single piece of equipment which would be capable of producing the M55 detonator at a rate of 800 to 1200 parts per minute (ppm), and be economically effective under mobilization conditions. Obviously, this approach necessitated investigation into many new and innovative methods for detonator production. As an example, factors such as powder metering, lacquer drying time, packaging, punch consolidation speed, process inspection, initiation hazards, etc. became major considerations at the speeds envisioned.

Specifics and/or reference to publications covering results of these early feasibility investigations into achieving high rates of detonator manufacture are presented.

As time progressed, changes in modernization payback philosophy (peace time versus mobilization) predicted costs for high rate equipment, and the desire for a less complex approach resulted in the redirection by higher headquarters of former efforts to a multisubsystem approach culminated in efforts toward the development of a quad-tooled loader with separate ancillary equipment (detonator cleaning equipment, inspection, material handling, traying, etc.). Specifics and/or reference to publications covering results of these efforts are presented.

DISCUSSION

Initial High Rate Investigation

Based on increase mobilization requirements for nonelectric detonators, a proposal¹ was prepared and submitted for an automated line for loading, consolidating, sealing, and packaging detonators at a rate of some 800 to 1200 detonators per minute.

The objective of the proposal was to have all operations and controls automated, thereby enhancing safety, increasing productivity, and reducing the number of operators. To increase system availability and reliability, all stations would be plug-in modules to enable quick repair. Prior to the submission of this proposal, nonelectric detonators such as the M55 were being produced in multiple stages at approximately 43 detonators per minute. In view of the demanding requirements of the new proposal, it was decided that the following sequential steps should be pursued toward the ultimate design and development of the newly proposed automated detonator line:

- Study available technology and equipment specifically designed for detonator production
- Study available technology and equipment that can be applied to the detonator production, although designed for other uses
- Formulate new techniques and equipment for detonator production
- Evaluate all techniques and equipment available or envisioned as concepts
- Design procedures and equipment for utilization of those techniques and concepts that are worthy of further investigation
- Construct and apply equipment that appears promising after evaluation
- Evaluate mockup stations
- Prepare specifications and requirements for optimum equipment

¹ "Engineering Proposal for the Modernization of Nonelectric Detonator Production Facilities", Ammunition Engineering Directorate, Picatinny Arsenal Dover, New Jersey, 1969.

Basic Technology Survey

Based on the preceding objectives, efforts were initiated with Gulf and Western Corporation, Swathmore, PA, for a survey of techniques and equipment for fully automatic production, 100% inspection, and packaging of nonelectric detonators. The 6-month survey consisted of a literature search of high volume, high-rate equipment and technology, and visits to the Army load plants and Picatinny Arsenal in addition to private equipment suppliers. The final report² reached the following conclusions and made the following recommendations:

Techniques and equipment are available within the state-of-the-art to construct a fully automatic 1200 ppm detonator line, except for several possible problem areas that will require some development work. The main problem areas which exercise the prime constraints on the choice of process techniques and manufacturing equipment are due to the following characteristics of the priming mix and high explosive powders used in the detonator manufacture:

- Sensitivity to initiating stimuli
- Explosive power
- Handling characteristics

Flow characteristics
Particle size
Dusting tendency
Bulk density
Uniformity
Hygroscopicity

Based upon the preceding constraints, the following specific recommendations were made:

- Use individual workpiece holders and move them continuously through the process line in a captive, oriented manner using rigid continuous transfer devices. Mount multiple work stations (tool modules) on rotary turrets to simultaneously process numerous workpieces at one time.
- Use mechanical presses with toggle linkage or Bliss "powerbar" for consolidation stations for best control of ram speed.
- Automate the "back line" to safely meet the demands of the "front line".

² "Survey of Techniques and Equipment for High Volume Automatic Production of Nonelectric detonators," Technical Report 4541, Picatinny Arsenal, Dover, New Jersey, 07801-5001, 5 February 1973.

- Use present gravity feed volumetric metering devices, Cargil scooper, Iowa dispenser, Chamless dispenser, etc., but try to improve accuracy and precision and reduce cost and frequency of "blows".

- Undertake a study to determine optimum consolidation rate, pressure, dwell, and tool clearances for each type of detonator explosive.

- Develop optimum barricades for each type of tool module, process operation, and inspection function; include dust control.

- Completely automatic, on line, 100% inspection is probably the most expensive feature of the envisioned modern production line and will require the most development effort. Automatic on-line functioning testers, leakage testers, and flaw detectors must be developed although equipment for dimensional inspection is within the present state-of-the-art.

- Develop remotely controlled maintenance, repair, and trouble shooting equipment using closed circuit TV.

- Initiate efforts to advance technology in these problem areas.

The following concepts for preparing the explosive charges were also reviewed and deferred in favor of the more state-of-the-art technique of dispensing and consolidating.

- Stamping out of charges from explosive preformed into sheets.
- Extruding of charges from explosive containing a gel additive.
- Silk screen method of printing layered charges.
- Preforming the explosive charge and electroplating the cup onto it.

Experimental Evaluation Phase

In this phase, areas with high anticipated difficulty factors, as well as others, were investigated. In this particular program, it was determined that explosive loading was one of the key potential problem areas. In keeping with this premise, three parallel efforts were pursued in metering, dispensing, and consolidating while other less demanding areas were relegated to a single approach. A brief summary of the efforts and results from the experimental evaluation phases follow. The efforts have been organized by the specific area being investigated (i.e., explosives loading, closure, packaging, etc.) as well as the contractors involved.

Explosive Loading (metering, dispensing, and consolidating).

1. MRC

A contract was given to MRC Corporation, Hunt Valley, Maryland, for the purpose of developing new techniques for the loading and consolidating of nonelectric detonators.³

The following four major objectives of the contract are:

- Perform an engineering study of the operation of loading nonelectric detonators
- Conceive new techniques and equipment to perform these operations at the rate of 1200 per minute
- Fabricate a bench model sufficient in details to establish the basic feasibility of MRC's gravity-feed, rotary press concept
- Perform inert and live tests using the bench model to demonstrate feasibility

One of the first steps taken by MRC to help meet these objectives was to subcontract with the Allegany Ballistics Laboratory (ABL), Cumberland, Maryland, for a hazards analysis. This study concentrated on two principal areas: the sensitivity of the three explosive powders (NOL-130, lead azide⁴, and RDX) and the safety of MRC's loading concept. Specifically, the tests performed included:

Friction

Electrostatic discharge

Human spark

Impingement

Dust explosibility

Thin film propagation

Taliani

³ "Conception of New Techniques and Equipment for Production of Nonelectric Detonators," MRC Corporation, Hunt Valley, MD, 1975, final report.

⁴ All lead azide referred to are type RD 1333 unless otherwise noted.

Differential scanning colorimeter

As a direct result of its analysis, ABL concluded that adequate safety margins existed to insure the normal operation of MRC's system. Moreover, if the critical values, as determined by ABL, for the possible failure modes of the MRC equipment were not exceeded, then the chance of a major explosion due to any one failure mode in 2-yr continuous operation would be limited to one part in one million.

To demonstrate the feasibility of its concepts, MRC constructed an experimental bench model, rotary compaction press (fig. 4). The main part of this press was circular dial plate approximately 16 in. in diameter that rotated at 24 rpm. A single die was placed in the plate into which the explosive powder would fall under the influence of gravity from a stationary feed frame (or powder reservoir) that contacted the upper plate surface. Detonator cups were fed to the upper plate surface in an inverted fashion in individual cylindrical carriers called nests. The nests were registered in position over the die cavity by an upper punch. A lower punch, activated by cams, pushed the powder in the die cavity into the cups and provided the necessary consolidation force. As the dial completed its revolution, the nests were taken off by an egress plough. Although only one station was used on this bench model, the rate of 1200 per minute could be attained by distributing 48 stations around the rotary dial table.

A series of inert loading runs with simulants were performed using the bench press which permitted mechanical checkout and debugging operations to be performed without the risks inherent with explosive testing. The simulants used were Borax/Wax for RDX, PVC for lead azide, and talc for NOL-130. At the successful conclusion of the inert simulant tests, live loading runs were initiated.

The first explosive tested (RDX) posed no significant problems. An Oilon PV-80 was used on the feed frame and two loading runs of 21 and 23 detonators were made. The quantity of explosive loaded varied from 40 to 44 mg which is in considerable excess of the nominal 19 mg specified for the M55.

The second explosive tested (lead azide) was more troublesome resulting in two detonations. After the first, the feed frame was modified to float on springs. After the second, a hardened aluminum bearing surface was substituted for the Oilon PV-80. These modifications improved performance to the extent that 67 detonator cups were subsequently loaded over a duration of 78 minutes without detonation. The quantity of explosive metered for the lead azide runs ranged between 21 and 30 mg or approximately half of the nominal 51 mg charge. Further testing to obtain 51 mg was not pursued because it was felt that the feasibility had been proven and a change in feed frame size or introduction of multiple compartments was all that remained to dispense the required charge.

The final explosive tested was NOL-130. Oilon PV-80 was used as the bearing surface for the feed frame. Bridging of the NOL occurred in these initial runs. To remedy this situation, a large, 5-compartment feed frame, incorporating undercuts and pneumatic agitation was introduced. Fifty-four tests were conducted with this configuration. Metered weights varied from 0 to 21 mg. The

nominal NOL-130 charge was 15 mg. Subsequent to these final modifications, one detonation occurred with the NOL-130.

The proposed detonator production system of MRC was based on the use of the basic metering, dispensing, and consolidating designs previously described, as well as, cup feeder, several starwheels for directional changes and transfer between turrets, QC turrets, sealing, and a nest recycle loop. Each proposed press consisted of 48 stations on a dial which rotates at 25 rpm. Each of the three explosive powders would have its own turret.

2. Bulova

Bulova, Valley Stream, NY, was awarded a contract to conceive techniques for metering, dispensing, and consolidating powder, and to build a conceptual bench model which would demonstrate feasibility with both inert and explosive powders⁵.

Bulova concentrated its effort in three separate areas:

- Study of several parameters of the explosive powders involved in detonator manufacture and of the inert powder simulants to be used in the initial testing
- Design and construction of a simple experimental unit (bench model) for on-the-fly metering and dispensing of powder
- Conceptual design of a pilot system which would encompass all operations of detonator manufacture from loading the cups to unloading the finished detonators

As the first step, Bulova undertook the study of the parameters of the three powders involved in detonator manufacture (RDX, lead azide, and NOL-130). Also studied were the following possible simulants for the explosive powders:

- RDX--Iodized salt and a mixture of borax, potassium sulphate, and graphite
- Lead azide--Pure superfine cane sugar and PVC
- NOL-130--Baby powder

The powders and simulants were measured to determine the following properties:

⁵ "Conception of New Techniques and Equipment for the Production of Nonelectric Detonators," Bulova, Valley Stream, NY, November 30, 1973, final report.

Granular size, shape, and distribution

Moisture content

Specific gravity

Bulk specific weight

Angle of repose

Electrical conduction and surface tension

Pelleting factor

Sensitivity to friction and impact

It was found that RDX Type B had the largest particle size, and no additional additives were needed to be added for direct dispensing. However, for pelletizing, a binder lubricant would be helpful. Lead azide had the tendency to interfere with moving parts due to its small particle size; therefore wipers and cleaning devices were deemed necessary. The primer mix (NOL-130) was particularly troublesome because of its inability to flow freely without outside stimulus. Based on these previously mentioned powder characteristics, Bulova recommended that the explosive powders be formed into pellets to facilitate handling and dispensing.

The second major task accomplished under the Bulova contract was the design, construction, and testing of an experimental centrifugal dispenser (bench model) for the loading of nonelectric detonators (fig. 5). This bench model consisted of a rotating dispenser head and an indexing table-magazine. Powder was provided by an air motor.

Having a radius of 4.79 in. and with a capacity of 150 detonators, the indexing table would advance one detonator spacing for each complete revolution of the dispenser. The dispenser contained a hopper for the bulk powder, a feeder metering valve for increments up to 10 charges, and a single charge metering valve. These were constructed to use centrifugal force to build up a head of powder. Also, a movable funnel in the dispenser served both as a tamping anvil and charge dispenser which would form pellets of charge at 3500 psi and then dispense them into the detonator cup to reduce powder spillage.

This bench model was tested with both simulants and live powders at speeds ranging up to 100 rpm. RDX was dispensed up to 63 rpm at 3500 psi with no blows, lead azide was dispensed up to 75 rpm at 3500 psi. However, NOL clogged in the dispenser and spilled out, but no detonation occurred. In Bulova's view, this substantiated the need for pelletizing the powder before dispensing.

The third principal topic was the proposal of a system concept for detonator production at 1200 ppm. Basically, this concept was composed of four rotary turret machines connected by a chain which carries the detonator cups. There are turrets for loading cups, powder dispensing (pelletizing), tamping, disc appli-

cation, and cup unloading. The dispensing (consolidating) turret would be very similar to the design of the bench model, operating at comparable speed but with 12 sets of tooling rather than the single set in the bench model.

3. FMC

A contract was awarded to FMC, Santa Clara, CA, for the conception of a systems approach to the loading, assembly, and inspection of nonelectric detonators and also for the development of experimental bench models.⁶

FMC constructed an experimental bench model for the metering, loading, consolidating, and crimping of detonators (figs. 6 through 8). Each of the four previous operations was accomplished on the same experimental machine with changes in tooling only. Although no blows occurred, some bridging problems were encountered with NOL. Accuracy was within \pm 5%. However, problems with erosion of the filter in the vacuum-nitrogen lines used for aiding filling and dumping of explosive were encountered.

As envisioned by FMC, a system for the production of nonelectric detonators would consist of 12 rotary turrets, 36 in. in diameter, linked by a number 80 chain which carries the cups at 4 in. intervals in holders. These turrets, each with modular quick change tooling stations, would rotate synchronously at 50 rpm, thereby performing 1200 operations per minute per turret. The 12 turrets as proposed by FMC would perform the following operations: 1 turret for loading cups, 3 for metering and consolidating the three powders, 3 for brushing and aspirating, 1 for disc blanking and insertion, 2 for crimping, 1 for sealant application, and 1 for unloading.

The heart of the FMC system concept is the loading station. There are three loading stations: one for loading each of the explosive powders (NOL-130, lead azide, and RDX). Each loading station consists of two of the previously mentioned rotary turrets. One turret, around which the carrier chain moves, is a rotary press for consolidation of the charge. The other turret is for the metering and dispensing of the explosive charge. The rotary press turret consists of 24 stations each having an upper punch that does the consolidation and a lower anvil punch that locates the detonator cup and carrier. The punch stroke and pressure are controlled by cam followers and springs. A linear variable differential transfer (LVDT) attached to the upper punch monitors punch movement and cup fill condition. The metering turret consists of a hub with 24 Delrin powder cups which rotates on a stationary column. A chain supply conveyor scoops explosive powder from behind barricades, off line, and deposits it in the Delrin cups one every 11 revolutions. Metering of powder is accomplished by a rotating shaft with a variable cavity which agitates the powder in the Delrin cup

⁶ "Design of a High-Speed Nonelectric Detonator Loading, Assembly, Inspection, and Packaging System," FMC, Santa Clara, CA, July 9, 1974, final report.

with bursts of nitrogen, then sucks the powder into the cavity under vacuum, rotates 180 degrees, and dumps under nitrogen pressure into the detonator cup on the rotary punch turret.

Crimping and Sealing

1. MRC

The MRC Corporation was awarded a contract for the purpose of developing new techniques for inserting the closing disc, crimping, and sealing nonelectric detonators.⁷

MRC's detonator sealing concept used three independent rotary turrets for inserting closing discs, crimping detonators, and lacquering the crimped end area. Each turret (similar to those used for dispensing, metering, and consolidating) consisted of 48 independent stations which revolved at 25 rpm. The entire turret, in each instance, is dedicated to performing one of the three required operations. Loaded detonators, housed in nests with the open end up, are introduced to the closing disc insert turret by means of a starwheel. Closing discs are punched and inserted directly into the detonator cups which are then transferred by a starwheel to the crimp turret where successive 45 degree and 90 degree crimps are performed. A third starwheel transfers the detonators to the lacquering turret where one drop of lacquer is applied to each detonator. Following this operation, the nested detonators are transferred to the packout area.

Bench models of the previously described system concept were constructed with only one of the anticipated 48 stations and then tested at a rate corresponding to 1200 ppm. Inert detonators were successfully sealed and crimped in test runs of up to 645 detonators. However, there were initial problems with input turret jams, foil advance mechanism jams, and "no disc" rejects. As a result of their inert tests and subsequent fixes, MRC recommended that live tests be made on the bench model, along with water immersion tests of sealing effectiveness, and firing tests of sensitivity and output. These tests with live material were proposed as part of a follow-on contract which would serve to finalize design criteria for a prototype machine.

⁷ "Development of High Speed Equipment for Sealing Nonelectric Detonators," MRC Corporation, Hunt Valley, MD, September 1974, final report.

2. Sonobond

The Sonobond Corporation (formerly Aeroprojects Incorporated), West Chester, Pennsylvania, was the second firm given a contract to investigate the sealing aspects of nonelectric detonator production.

The objective of this contract was to demonstrate that nonelectric detonators can be sealed at the rate of 1200 ppm through the use of ultrasonic ring welding equipment. To achieve this goal, development of ultrasonic welding equipment was initiated. Furthermore, a modified detonator cup incorporating a 90 degree flange on the open end was designed, as was the requisite tooling. However, the foregoing equipment was never proved out due to financial difficulties encountered which precluded further work under the contract.

Packaging and Packout. A contract for detonator packaging was awarded to the FMC Corporation. A summary of the tasks accomplished under this contract is outlined in a final report.⁸

FMC surveyed current GOCO plant operations and determined that existing packing methods and operations could not be adapted to high production rates. A study of related technology in the packaging and pharmaceutical industries also proved fruitless. Therefore, FMC embarked on a program to develop and prove out its own packaging concepts. As part of this program, FMC fabricated and tested four bench models that performed the following functions:

1. First Model

- Transfer of detonator, without losing longitudinal orientation from assembly line to packaging line, using nylon-disc carriers
- Transformation of single file motion to 10 abreast motion, using a transverse shuttle.

2. Second Model

- Transfer of detonators from carrier discs to nests in the bodies of inner setup boxes, using a manifold punch

⁸ "Development of Equipment for Automated Detonator Packaging," FMC Corporation, Santa Clara, CA, October 1974.

3. Third Model

- Insertion of detonator-loaded bodies of inner setup boxes, together with release papers and felt cushion⁹, into slide covers

4. Fourth Model

- Accumulation of 20-box lots of inner setup boxes and insertion of each lot into an outer setup box

As a result of these tests, the following conclusions were developed:

1. Feasibility of the critical components of the conceptual system was proved.
2. Use of heat-stabilized nylon discs provided an inexpensive means for transferring detonators from assembly line to packaging line, preserving the longitudinal orientation of the detonators
3. Mechanization beyond the vacuum sealing of outer setup boxes is not economically justifiable for a production rate of 1200 detonators per minute.

Hazards Analysis

In keeping with the sensitive nature of the detonator material, a contract was awarded to Allegany Ballistics Laboratory (ABL) for a comprehensive hazard analysis of the experimental areas pursued.⁹

ABL pursued four principal areas of investigation: backline, loading equipment, sealing equipment, and packaging equipment.

The backline studies covered an analysis of the "Turbulator" which prepares a slurry of explosive, water, and alcohol for pumping between stations. Also covered with the "Roliex", which is used to wash and dry the explosive in production increments. Loading equipment subjected to a hazards analysis included the three bench model loaders, which were designed and built by MRC, FMC, and Bulova, respectively. The analyzed sealing equipment included MRC's three modules: disc insertion, crimping, and lacquer application. Finally, the detonator packaging equipment, developed by FMC in bench model form, was also subjected to an engineering hazards analysis.

⁹ "Hazard Analysis of Nonelectric Detonators Front and Back Line Operations," Allegany Ballistics Laboratory, Cumberland, MD, December 1975, final report.

In view of the considerable variety of equipment subjected to hazard analyses, the conclusions reached and recommendations made by ABL were, as expected, quite extensive. However, by concentrating on the common characteristics of the detonator loaders, some general conclusions can be reached.

All of the detonator loading concepts involve the use of continuous-motion rotary turrets mounting cam-actuated multiple tooling stations. Features recommended by ABL for any production loader include: sealed bearings for the turrets and cam followers, inspection to assure that detonator cups are present in the correct configuration and orientation, adequate barriers for protection against blows, reliable retention of punches in punch holders, and the inclusion of stringent safeguards against electrostatic hazards. Additionally, any dust aspirators used should include humidification to control static, and should limit particle impingement velocities to below the lead azide critical value. It is also important that friction between the punch and next surface (die, detonator cup, or guide) be a minimum. Friction pressure for steel on steel with tetracene should be limited to 15 psi or less if the probability of fire or explosion is to be limited to 1×10^{-6} over a year's duration. Pressures to 130 psi could be tolerated if one surface is aluminum. Aluminum on aluminum is not recommended since galling might possibly occur.

In addition to an analysis of the hazards common to the three detonator loaders, ABL produced a study of the hazard peculiar to each of the concepts produced by FMC, MRC, and Bulova. The following is a brief summary of the hazards inherent in each of these concepts.

There are three major hazard areas present in FMC's detonator loading concept. The carrier and return spring is the most serious, since it may cause several fires and/or explosions per year. Constant cycling and high friction forces are the prime initiating mechanisms. The second principal hazard is the friction which occurs between the metering rod and its seals. It is anticipated that at least one fire or explosion will occur in the course of one year's continuous operation due to this malfunction. The final area of concern is that of the dusting of explosive powder resulting from metering action and turret rotation. It is recommended that windshields be devised or other modifications be made to aid in dust control.

In the judgment of ABL, a number of potentially hazardous features exist in the Bulova loader. First and foremost is the metering punch holder. Powder can work into the gap between the holder and the table, resulting in a possible explosion or fire in the course of one year's operation. Secondly, a movable funnel is used in the Bulova loader. High friction forces per unit area occur, giving a rise to a unity probability that a fire or explosion will occur once during a year. Reduction of rubbing pressure would reduce this probability. Finally, it is recommended by ABL that the spring loaded press cam follower be as nearly flush with its boss as possible to reduce the impact and probability of fire and explosion.

The MRC detonator loader has a number of potentially hazardous characteristics associated with its design. First, feed frame pressure against the dial plate must be limited to less than 10 psi in order to preclude initiation.

Secondly, consolidation punch pressure in the detonator cup should be limited to 10 psi. Any high pressures could conceivably cause a blow resulting from rotation of the cam follower on the compression roller. Friction will exist between elements of the special feed frame gimbal mounting planned for lead azide use, and also between the cam and cam track. Dust control would reduce probabilities of fire or explosion in these areas, as would changing to roller cam followers and substitution of aluminum material for some gimbal elements. Without these changes, probabilities of initiation range upward to several per year. Steps should be taken to avoid contamination above the lower punch holder and below the lower punch die. Initiation here could pose severe personnel hazards. Finally, assembly of the die in the dial cavity should be flush to within 0.0005 in. in order to preclude friction or the escape of powder.

Pilot Line Design Efforts

The results of the prior equipment survey, experimental bench modeling efforts, and hazard analyses are basically summarized as follows:

- Feasibility was established for handling, feeding, and compacting primary explosives (NOL-130, primer mix, lead azide) and RDX in M55 detonator cups at rates approximately 800 to 1200 ppm.
- Feasibility was established for disc insertion, crimping, and sealing nonelectric detonators at rates approximating 800 to 1200 per minute.
- Feasibility was established for a semiautomated packing system design.
- Overall systems design and interface was established.
- Seven experimental bench models were tested with satisfactory results:

FMC loading model

MRC loading model

Bulova loading model

FMC packing model

MRC disc insertion model

MRC sealing model

MRC crimping model

- Hazard analyses were conducted on design concept models.

• Basic design features were established for pilot line capable of loading 800 to 1200 detonators per minute.

Using the preceding results as a background data base, a request for quotation was prepared and distributed for an integrated automated detonator manufacturing line. A summary of the design goals for the proposed integrated system are as follows:

- 1200 ppm normal run rate
- Full automation from feeding of cups through packing of cartons, remainder of line mechanized
- Interchangeable tooling and machines
- Quick change tooling (5-min maximum)
- Quick change machines (4-hr maximum)
- Individual line run with 5-men maximum
- Automated inspection (100%)
- Preventive maintenance (2-hr max/day)
- Improved powder metering accuracy and precision
- One intersubmodule storage (buffering) specified and intrasubmodule storage to be analyzed during design and demonstration tests.
- 16-hr duty cycle, shift/day

The request for quotation (RFQ) which made available all prior efforts and data to all the bidders, requested that the proposals for the integrated line be separated into a pilot and prototype phase. These phases were subdivided into concept, design, build, and test work packages. A review and evaluation of the responses to the RFQ led to the award of the initial efforts to FMC. These initial efforts basically covered the submission of a concept for a prototype line encompassing those operations (manufacturing and inspection) that are necessary to load and seal M55 stab detonators at some 1200 ppm along with the design of a pilot system which would be capable of demonstrating the principles of the conceived prototype line while operating at a reduced output (100 detonators/minute). Although rate goal of the pilot line output was reduced from 1200 to 100, each process operation in the pilot line design was to be performed at an actual speed of 1200 detonators per minute. The 1200 detonators per minute prototype would have a multiple number of tools performing the same operations demonstrated on the pilot line. In conducting the preceding concept/design effort, FMC became involved in bench modeling additional areas which were considered to be high risk (e.g., cup feeding/singulation and powder dispensing). A detailed description of the proposed prototype concept and pilot line design is provided in Volume II, appendix A. A summary of the work accomplished in this initial contractual phase is as follows:

- Current production processes and facilities were reviewed.
- All work previously accomplished by Picatinny Arsenal and others on this particular development were reviewed.
- An overall system concept encompassing manufacture and inspection operations necessary to load and seal M55 stab detonators from the feeding of metal cups through the drying of sealing lacquer at a rate not less than 1,200 ppm was developed.
- A preliminary design for a pilot line to demonstrate the conceived system to produce M55 detonators at a rate of 100 ppm was developed.
- A system analysis, including reliability and maintainability predictions for the pilot line was initiated.
- A hazards-analysis program was initiated.
- A program for the remaining phases, detailing all key events, decision points, feasibility models, and test activities with a narrative, calendar schedule, and abbreviated PERT form, was developed.

As indicated, the next sequential step would have been the build, debug, and test of the pilot line followed up by the fabrication of the prototype line. However, due to changes in payback philosophy, predicted costs for high rate equipment, and the desire for a less complex approach, it was deemed advisable by higher headquarters to hold this program at its present state and pursue a less complex multisubsystem approach. As such, the pilot line efforts ended at the point of pilot line design. Wherever applicable, information derived from the pilot line design effort was applied to the alternate multisubsystem approach.

In-House Support Activities

In an effort to reduce some of the design risk associated with the desired high rate of detonator production, the following supportive in-house programs were conducted.

Iowa Loader Characterization. One of the first programs investigated was that of determining whether the environmental forces created by the newly envisioned increased rate equipment would have a detrimental effect on detonator functioning. Areas of concern were approach velocities of rams on the various powders during consolidation, use of a powdered RDX instead of a prepelletized version, and the effects of centrifugal forces on the detonator powders (i.e., would the centrifugal force associated with the high rate equipment result in such an uneven distribution of powder in the detonator cup as to result in an unacceptable density after consolidation). Details of the investigation along with specific results are presented in Volume II, appendix B. The conclusions of the effort can be described as follows:

- Approach velocities of the consolidation ram for the proposed increased rate equipment is less severe than the present detonator production equipment. Tests on detonators loaded at the proposed extreme ram consolidation speeds yielded acceptable results.

- The effect of centrifugal force on the loose explosive/powders did not pose a problem in uniform consolidation.

- The utilization of loose RDX as opposed to the prepellitized version has no effect on detonator functioning.

One additional spinoff, investigated under this program was that of the general correlation between the standard detonator acceptance test and two new potential inspection techniques which could be more readily applied to increased rate production (i.e., particle velocity and gamma ray densitometer techniques). Based upon the limited testing conducted, the particle velocity technique appeared to offer general correlation while the densitometer technique would require more intensive testing.

Lacquer Investigation. As previously stated, high rate manufacture of detonators requires reduced manufacturing times for all aspects of detonator production. One such area is the time required for lacquer drying (5 to 17 min). Under normal production conditions, this time is not excessive; however, at anticipated rates of 800 to 1200 detonators per minute, this drying time should be reduced. In order to accomplish this, an investigation was conducted into existing lacquers, new lacquers, and various thinners.⁹ The investigation included experimentation with solids contents, viscosity measurements, film flexibility, permeability, and film thickness as related to drying times.

The investigation concluded that general purpose nitrocellulose lacquers will meet a drying time of less than one minute when reduced with acetone. The resultant protective film from this process provides a good barrier to water, both vapor and liquid. An additional outcome of the investigation was a recommendation that in order to assure high speed drying under a variety of temperature and humidity conditions, mildly heated substrates would be used along with forced air circulation in an exhaust system for solvent fumes.

Follow-on cursory efforts to apply the fast drying acetone thinned lacquer process under load plant conditions resulted in the conclusion that the present lacquer application method appears to be too operator sensitive to assure that a uniform coating has been deposited. This, in turn, effects the fast drying time repeatability. Therefore, should this technique be pursued for high speed deton-

⁹ Tanner, William C., "Evaluation of Cellulose Nitrate Lacquer for Use in High Speed Production of the M55 Detonators," Memorandum Report ARLCD-MR-78002, Picatinny Arsenal, Dover, NJ, November 1978.

ator production, consideration should be given to devising a closed system for lacquer dispensing.

Follow On Modular System Development

Changes in the detonator modernization payback philosophy (peace time vs mobilization) along with the desire for a more basic state-of-the-art approach led to the redirection by higher headquarters from the initial high rate (800 to 1200 detonators/min) technology efforts to a reduced rate (150 to 200 detonators/min) modular detonator system approach. This concept (fig. 9) consists of a multitooled version of the existing Iowa loader integrated with supporting ancillary equipment (i.e., detonator cleaning, inspecting, packing, and material handling). Along with these basic efforts, supportive investigations were conducted into multitooled loader improvements, ultrasonic sealing, metering accuracy, improved aspirate system, explosive resupply, and associated hazard analysis. The following portion of this report is arranged in a manner whereby each of the preceding modules and supportive efforts to the modified detonator system are addressed by a separate section.

Multitooled Loader and Improvements

The multitooled detonator loader selected for this modular system approach is basically an outgrowth of a development to upgrade (quad tool) the single-tooled Iowa loader. The output design rate for the quad tooled (commonly called X-4 loader) is 150 detonators per minute. The X-4 loader (fig. 10) uses the basic chassis and dial of the Iowa single-tooled loader and expands the capacity of each station to perform work on four detonators at a time. The loader is designed around the Swanson Erie No. 24M560 chassis. The index unit is a crossover cam type with 24 indexes, 90-degree dial index, and 270-degree dwell. The index accuracy of ± 0.0015 in. at dial radius of 27 in. and the unique reciprocating center column makes this unit ideally suited for detonator production. Eleven of the sixteen active stations are driven and controlled by the center column. A lower and upper tool plate straddle the indexing dial on which all of the stations are mounted. The stations perform the following functions for each machine stroke:

- (Station 1) Feed into the dial tooling and detect the feed of four detonator cups.
- (Station 2) Transfer four powder guides or funnels from a rest position to the dial tooling and electronically check for proper transfer.
- (Station 3) Open
- (Stations 4, 5, and 6) Remotely and accurately meter a charge of NOL-130 into each cup with provision for remote replenishment of the explosive powder.

- (Station 7) Consolidate the NOL-130 to a predetermined pressure while electronically monitoring the resulting powder height and pressure, rejecting out-of-tolerance units.

- (Stations 8, 9, and 10) Remotely and accurately meter a charge of lead azide into each cup with provision for remote replenishment of the explosive powder.

- (Station 11) Consolidate the lead azide as in station 7.

- (Station 12) Aspirate the dial fixture and the powder guide rests.

- (Station 13) Return the powder guides to their original position and electronically insure their proper placement.

- (Station 14) Feed and seat a RDX pellet into the four detonator cups.

- (Station 15) Consolidate the RDX as in station 7.

- (Station 16) Aspirate the dial fixture and powder guides.

- (Station 17) Punch foil discs from a roll and place them on top of the RDX charges.

- (Station 18) Inspect for foil and signal for rejection of units without foil.

- (Station 19) Form a 45-degree starting crimp on each of four detonators.

- (Station 20) Aspirate the dial station and powder guides.

- (Station 21) Seal four detonators using a flat crimp tool which completes the crimp.

- (Stations 22 and 23) Remove the detonators from the machine, separating rejects from the acceptable product. This station also places the almost complete detonators in an aluminum transfer tray whose dimensions match those of the nonpropagating pack. These intermediate trays are then carried by means of a transfer conveyor to an inspection barricade where the detonators are manually inspected and transferred to the nonpropagating pack.

- (Station 24) Aspirate the dial, dial station, and powder guides. The dial station tooling anvils are cammed up to facilitate cleaning.

Advantages of the X-4 to the conventional single-tooled loader, over and above the obvious increase in production output rate, are:

- Pressure ram modules use hydraulic pressure instead of die springs to control consolidation. This provides the advantage of consolidating to a specific pressure. Also, any pressure over the operational range can be varied by merely dialing in a new value.

- Load cells are used to measure the consolidation force applied to each powder increment.
- Microprocessor control and automated readout of functions such as: number of machine cycles, number of detonators accepted, display of selectable stored data such as average consolidation heights, etc.
- Lower velocity of punches during consolidation.
- Traying of detonators--X-4 loader has the capability to place detonators in a 40 hole aluminum tray.

At the conclusion of the MMT phase, a series of reliability/acceptance tests were conducted on the X-4 prototype loader where the design was accepted with six additional X-4 loaders procured for the modernization of line 4A at Iowa.¹⁰

During the MMT program, the following improvements to the basic X-4 loader prototype were investigated:

- Redesign input-output cards to take advantage of a newer card design
- Redesign powder barricades to allow for replenishment of both lead azide lead and NOL-130 during machine operation
- Design alpha numeric machine fault indicators for the control panel
- Redesign dial to allow for access after the primer consolidation station
- Redesign air amplifier cabinet to allow for installation of air regulators
- Design battery memory backup to avoid memory loss during power outage
- Redesign brake mechanism for powder guide transfer mechanism
- Redesign cup feeder entrapment to eliminate cup transfer problems
- Redesign RDX feeder to increase the capacity for RDX pellets

Of the nine preceding improvements, six were actually incorporated on the prototype X-4, the remaining three items were designed only and incorporated on the six loaders to be procured for the Line 4A detonator expansion project. The

¹⁰ Details on the X-4 loader are available in the Mason & Hanger Silas Mason Company, Inc., Middletown, IA, 31 August 1979.

following items were actually incorporated and tested on the prototype loader:

- Redesign of powder barricades
- Redesign of dial
- Design of battery memory backup
- Redesign of brake mechanism for powder guides
- Redesign of cup feeder entrapment
- Redesign of RDX feeder

Input-Output Cards. The redesign of the control system to accept new input-output (I/O) cards was accomplished but was not included in the X-4 prototype prior to the final 40-hr test due to time constraints. These changes were included in the six X-4 loaders procured for Line 4A. Prior to redesign, two rack drawers were required to contain 17 microprocessor and interface cards. Each I/O card required an output interface card and an input interface card. Many problems and considerable downtime occurred because of failures in this maze of cables and interface cards.

Based upon the redesign, one 16-slot rack is now sufficient to contain the required I/O cards. Three output cards and four input cards with built-in interface circuits are capable of replacing nine cards in the original system which leads to reduced complexity and increased reliability.

Powder Barricades. The dispensing barricades originally placed on the prototype loader had several problems which required redesign. Both barricades for lead azide and primer mix were vented through the roof. During long cold periods, heat loss was significant and condensation would form on the barricade surface in the required 60% relative humidity environment with the potential for adding moisture to the dry powder. The pipe used as a basis for the barricade was 18 in. in diameter and restricted access to the dial. A vent between the inner and outer compartments of the barricade would allow a detonation of the quantity of powder in the dispenser to vent into the receiving compartment which prohibited the replenishment of powder while the machine was in operation. The redesigned barricades were 16 in. in diameter, nonvented steel pipe, 3/8 in. thick, which eliminated the need to vent through the roof solving the condensation problem. The smaller diameter pipe allowed more space to work around the dial. The lead azide dispensing barricade is essentially the same design as the primer mix dispensing barricade. The test of the barricade design is included in Volume II, appendix C. Five tests were carried out with quantities of C-4 explosive of equivalent value to 125% of the quantities of initiating explosive for which the barricade was being proof tested. As stated in the report, the testing was successful and these barricades were included in the procurement package for the six X-4 loaders provided for Line 4A.

Alpha-Numeric Fault Indicators. Design for the alpha-numeric fault indicators was accomplished and installed on the six X-4 loaders for line 4A. The 16 malfunction lamps gave just a hint of why the loader stopped. The "cup feed" light gave a good idea of the problem but such lights as "auto pack" covered a lot of problems. Also, from the loader, the operator could not see which lamp was lit. The alpha-numeric display shows the operator the exact cause of a shutdown. An example of a reasonable message is: POWDER GUIDE IS TOO HIGH AT STATION 3. The display is large and bright enough to read from the loader. This new console is considered a vast improvement over the original.

Dial Redesign. To redesign the dial to allow for access after the primer consolidation station, a study of the dial layout concluded that the 16-in. diameter barricade pipe with the azide shield offset would allow the required dial access immediately following the primer consolidation station.

Amplifier Cabinet and Memory Backup Redesign. Redesign of the air amplifier cabinet and provision of a battery memory backup were deleted because they were not necessary.

Powder Guide Transfer Mechanism Brake. The powder guide transfer mechanism consists of a belt-driven cam with a series of levers and connecting links that lift and translate the powder guide transfer head. The cam overtravelled because of its inertia thereby caused misplacement of the powder guides. The brake mechanism is composed of an air cylinder and brake pad as well as a proximity sensor. When a lug on the cam actuates the proximity switch, the air cylinder engages the brake pad with lugs also on the cam, properly positioning the cam to prevent overtravel. This system has proven to be effective.

Cup Feeder Entrapment. The redesign of the cup feeder entrapment actually involved minor improvements to the mechanism, primarily with the vacuum porting to enhance the fixtures ability to grasp the cup prior to the punch placing it in the cup nest.

Increased RDX Pellet Replenishment. In an attempt to reduce downtime for replenishment of RDX pellets, a small door was placed in the large access door at the RDX pellet feeding station which would permit replacement of empty RDX pellet tubes without shutting down the machine. Each tube contains about 250 pellets and the machine holds six tubes for a total of 1500 pellets. Without this improvement, the machine would be shut down every 10 minutes for replenishment, at the rate of about 150 detonators per minute. Therefore, this simple solution has significantly increased productivity.

A 40-hr demonstration test was run on the X-4 loader (table 2). Total production per 8-hr shift ranged from a low of 22,612 detonators (M55) to a high of

39,372 detonators. The machine reject rate had a range of 4.8% to 7.8%. The total production shift average was 33,237 units, and the total accepted shift average was 31,101 with a combined reject rate of 6.4%.

Inspection Module

The need for automated inspection is considered a key area because of the labor intensive nature of the operation. A listing of the detonator defects and present inspection methods is provided in table 3. The defects are varied and require extensive and unique inspection techniques to render them suitable for automation.

To obtain as much exposure to the inspection problem as possible, a qualitative requirements information (QRI) problem was issued. Through this approach the detonator inspection problem was surfaced to some 685 companies. As a result of this action, a number of proposals were received and evaluated, an award made to MRC Corporation of Maryland for the design and development of an electro-optical prototype inspection module. A two-phase development program was initiated with MRC: first phase was to establish and demonstrate a feasible inspection concept; second phase was to actually design, build, and test the prototype inspection module. At the conclusion of the first phase, the concept selected was an image evaluation system that uses a line scan charge coupled device (CCD) camera for data acquisition and an analog computer as the data processor. In operation, detonators are fed to a vertical dial (ferris wheel) 30 inches in diameter with 24 Vee shaped nests. The Vee nests provide transportation of the detonators to the CCD camera viewing stations as well as positioning and nesting for end and side scanning rotation. Rotation is accomplished by an air motor. Contact between the detonators and the air drive motor is made through a vacuum clutch.

Throughout the development program, technical problems, traceable to parts handling and illumination, severely curtailed progress and resulted in time and cost growths.

In a final effort to resolve the preceding development problems, a two-step amendment was issued. Step 1 called for a system demonstration test of solely the inspection aspect of the equipment (i.e., material handling was not required). The equipment was to be modified with improvements from an internal MRC independent research and development program (IRAD) on a new viewing method and an improved nesting configuration. The improved IRAD viewing method (Dove prism) eliminated the need to rotate the detonator for end view scanning. In this technique, the optics rotate instead of the part being inspected. Step 2 was to complete all workup through and including System Preliminary Acceptance Tests at MRC. Although the changes resulted in some improved performance, it was decided that the resulting reliability and accuracy of the system did not lend

itself to usable on-line inspection equipment. These results coupled with the advances in technology which occurred since the inception of the inspection program led to the decision that the present inspection module program be terminated and recommendations for new efforts be made based on the latest technologies and lessons learned.¹¹

As part of the termination, an evaluation of the design of the inspection module was conducted. Problem areas that resulted in failure of the equipment to satisfy the requirements were surfaced and analyzed. Alternative methods for providing the required inspections using lessons learned and current technology were addressed. Details of this analysis can be found in the actual evaluation (vol II, app D). Recommendations for future systems are as follows:

1. The line scan inspection station should have a fixed detonator nest accurately aligned with the optical system. The nest should not be part of the transport mechanisms.

2. The nested detonator should not contact fixed surfaces when it is being rotated for scan inspection. The detonator must have freedom to rotate so that erratic motion will not be induced.

3. Side-view and end-view scan inspections should be incorporated in the same station. Two scan cameras and two illumination subsystems will be required; however, transport problems will be lessened with only one location for both inspections. Both inspections should be performed simultaneously.

4. Detonators to be inspected should be illuminated with collimated light. Use of fiber optics to transmit the light from the source to the surface of the detonator should be further evaluated. High intensity incandescent or strobe lighting should also be evaluated.

5. The CCD video line scan camera should have a resolution of 1024 x 1 or 2048 x 1 pixel resolution. The lens system should be selected as dictated by physical position relative to the subject and lighting.

6. The control system and decision making electronics should be "user friendly" and should be capable of operation in a production plant environment without constant attendance by hi-tech computer science skills. State-of-the-art equipment that is standard and available "off the shelf" is preferred to custom designed and fabricated equipment or subsystems.

Programmable controllers and microprocessors are preferred over dedicated controllers and micros where the user program is burned in and cannot readily be changed.

¹¹ Technical progress summarized in "Detonator Inspection System," Interim Report 736 SER, MRC, Hunt Valley, MD, June 1, 1983.

A concept for a design which incorporates the features discussed in these recommendations is presented in appendix D.

In the initial approach (QRI), it was recognized that the development of an inspection module would be an involved task. Although the inspection effort was not completely successful, the preceding shows that much of the work and associated results offer considerable value from a lessons-learned aspect to both follow-on as well as similar inspection efforts. Furthermore, many of the associated efforts such as pneumatic transport and propagation studies find application to other programs which require the handling of detonators in their assembly (e.g., fuzes and grenades).

Future efforts on inspection should consider the preceding technical recommendations from the lessons-learned evaluation along with the following general recommendations:

1. Improved characterization of detonator visual defects for machine interpretation should be developed.

2. Automated inspection techniques provide the capability to take a vast number of dimensional readings at very small increments (0.0004-in. bands). Any slight surface fluctuations on the edges or ends of the part may result in an excessive dimensional variation. Gaging philosophies in this area should be explored to cover possible techniques of averaging or limiting the number of readings, etc.

3. Another inspection criteria to be explored further is the sampling versus 100% inspection of other than critical defects. With automated inspection, once the part has been captured for critical inspection, it follows that major and minor inspections also be conducted on a 100% basis. This premise may require further examination for follow-on systems.

Inspection Module Supportive Efforts--Pneumatic Transport and Propagation Studies

As part of the detonator inspection module program, a great deal of supportive effort was expended in the areas of pneumatic transport and associated propagation tests for the module as well as the material handling infeed and output subsystems.¹²

¹² "Special Report Pneumatic Transport of M55 Stab Detonators", Report 736-2A, MRC Corporation, Hunt Valley, MD, September 1979.

"Nonpropagation Test Program for M55 Stab Detonator, F. McIntyre, Computer Sciences Corporation, R. Rindner and W. Stirrat, ARRADCOM, December 1981.

Pneumatic Transfer. A number of methods were considered for feeding detonators into the inspection module. Because of timing and geometry constraints, pneumatic transfer emerged as the most viable candidate. In keeping with this, a number of experiments were conducted to insure the suitability of this technique. Experiments were carried out for the following purposes:

- Verify general operation of the proposed in-feed design
- Verify capability of the proposed in-feed design to transport live detonators
- Evaluate the possibility of in-feeding two detonators at the same time. This affects the design of a piece of interfacing equipment.

The experiment was organized in two phases: (1) restricted to inert testing in order to acquire data concerning the dynamics of the process, (2) concerned with the testing of live detonators to verify system performance.

The test setup (fig. 11) consisted of a length of 0.170-in. inside diameter plastic tubing to transport the detonator contained within an outer lexan tube for detonation protection. The length of tubing was instrumented to record average detonator velocities between measurement points. Positive pressure for detonator transport was controlled by a pressure regulator.

Much information relative to required pressures to achieve desired velocities of detonators was obtained along with other design criteria required for the prototype inspection module.

In general, conclusions from the effort are as follows:

1. Pneumatic transport of detonators in plastic tubing by positive pressure was successful.
2. Actual transport closely approximates movement by positive displacement of air; the part being transported does not accelerate over the full length of travel.
3. Transport of two detonators at a time in parallel systems is feasible.
4. The use of a smaller inside diameter tube would produce a very high level of repeatability and control (diameter used for test was 0.170 in.).
5. Physical parameters of the transport tubing (such as roundness of the inner diameter) are important. Tubing procurement may have to be controlled by specification.

Nonpropagation Test Program. As part of the effort to provide safety data for support of modernization activities, a series of tests were prepared and

conducted for the MRC inspection module which included in-feed and material handling configurations as well as the basic detonator module itself. The test program was divided into the following six phases:

1. Input/Output Transfer Tests--The objective was to determine the effectiveness of a Lexan protective shield which covers the small plastic tubing during detonator pneumatic transfer (i.e., would the outer shield remain intact if one or more detonators were initiated during transport?).

2. Intratray Propagation Tests--The detonators as received from the X-4 detonator loader come in a 50-hole aluminum pallet. The pallets are transported on a conveyor belt covered with a Lexan shield. The objective of this test was to determine the optimum height for the conveyor belt shield to preclude fragments from an initiating detonator starting a chain reaction.

3. Indexing Dial Spacing--The detonator inspection module transports detonators within the module on a vertical dial (ferris wheel). The dial has nests spaced along the circumference of the dial which houses the detonators. The objective of this test is to insure that the dial spacing and associated shielding is sufficient to avoid propagation.

4. Rejected Detonator Container--Rejected detonators from the inspection module are fed to a container within the module. The objective of this test is to determine the structural integrity of the container and the maximum quantity of detonators in the event of initiation.

5. Indexing Dial Nest Integrity Tests--The inspection machine indexing dial receives detonators by means of a pneumatic transfer. Normal pressure is 50 psi and maximum pressure in the event of regulator failure is 100 psi. The objective of this test is to run confirmatory tests in this configuration.

6. Shipping Tray Integrity Tests--Upon completion of inspection by the module, the detonators are pneumatically transported to a 50-hole cardboard pallet (final shipping container). The objective of this test is to conduct confirmatory tests at maximum pressure (100 psi).

Some basic conclusions for this effort are as follows:

1. The results of the input/output transfer tube tests determined that an outer shield constructed of Lexan tubing with an outer diameter of 38.1mm (1.5 in.) and an inner diameter of 32.0 mm (1.26 in.) is effective when two donors and two acceptors in adjacent inner plastic tubes ignite simultaneously. Therefore, a maximum number of four detonators can ignite simultaneously without rupturing the outer shield.

2. Intratray propagation can occur when a single detonator is initiated. The minimum shield height to prevent intratray propagation is established as 50.8 mm (2 in.) above the tray surface.

3. The MRC spacing of 50 mm (2 in.) between detonators on the inspection dial is sufficient to preclude propagation in the event of an accidental

initiation.

4. The results of the rejected detonator container tests indicate that a maximum of 300 detonators is the upper limit to preclude serious damage to inspection machinery.

5. The results of the indexing dial test indicate that there is no detonator reaction upon transfer to the dial nest at transfer rates up to 13.7 m/s; however, the metering valve setting is critical.

6. The results of the shipping tray integrity tests indicate that a safe transfer is possible when using the MRC metering valve, and the setting on the valve should not exceed the number 2.0 setting.

Material Handling and Detonator Cleaning

Concurrent with design and development of the inspection equipment was a design and development effort for a material handling system to automatically clean, transport, and transfer the M55 detonators to the inspection equipment and then on through to packout. This detonator cleaning and material handling system was designed and developed in-house using the engineering, procurement, manufacturing, and management resources at ARDEC (fig. 12).

A concept of the modular nonelectric detonator modernization system beginning with the Iowa multitool loader and ending with packout is shown in Figure 9, a conceptual sketch of the prototype material handling and detonator cleaning system in figure 13, and a photograph of the prototype inspection module in figure 14.

Since only one prototype inspection module was being developed, the scope of the material handling system design included a capability for one inspection module; however, the frame of the machine was manufactured with space and mounting hardware for the three additional inspection modules.

The material handling and detonator cleaning system was designed, developed, tested, and shipped to Iowa Army Ammunition Plant for final installation and integration with the remaining portions of the system.

The following is a brief summary of the various subsystems of the material handling and detonator cleaning system:

Conveyor. Uses the two off-the-shelf units with 6-inch wide continuous, parallel flat belts. The belt is continuously moving except for an emergency stop or normal shutdown. Pallets or trays are stopped at the work stations by means of mechanical gates; the pallet slips on the moving belt while stopped by the gate.

Indexer. Mechanism receives the pallet from the belt and positions it

under the vacuum transfer line of the inspection module. The indexer sequentially steps 10 times. At each step, two detonators are removed from the pallet by the vacuum line and transferred to the inspection module for processing. When all 10 detonators in a line are removed, the pallet is placed back on the conveyor to be transported to the next inspection module where the next line of 10 detonators is removed and so on until all four detonator rows on the pallet are empty.

The indexer step action is driven by a stepping motor and associated step motor controller. The indexer sequence is controlled by the programmable logic controller (PLC) and its associated software (fig. 15).

Cleaning Station. The pallet is stopped at the cleaning station and held in position by a gate mechanism. A brush driven by an explosion-proof motor is swept across the surface of the tray of detonators for the purpose of removing residue explosive composition. A vacuum line is used to remove the loosened explosive compound.

Tray Transfer. The mechanism transfers cardboard trays with detonators from the tray conveyor to the pallet conveyor. From this point, they are transported to the lacquer and packout stations. This mechanism uses a long stroke-cable drive pneumatic cylinder to move the trays across from one conveyor to the other (fig. 16).

Control System. The heart of the control system is a Texas Instruments TI-103 programmable logic controller. This controller has a 2000-word memory and a maximum 256 I/O capacity. The TI-103 also has the capability of using time, counter, and shift register functions in the software.

The basic program controls the output device such as solenoid valves, motor starters, step motor controllers, etc. in an operating sequence provided by programmed input devices such as proximity switches, photo-electric detectors, and manually operated control panel switches. Machine status is displayed on control panel indicator lights which provide operating parameters such as auto mode, manual mode, emergency stop, etc. (fig. 17).

Safety Analysis X-4 Multitooled Iowa Detontor Loader

As part of the modular system development effort, a contract for conducting a safety analysis of the X-4 Iowa detonator loader was awarded to Allegany Ballistics Laboratory (ABL), Cumberland, MD. The operations, equipment, and personnel hazards were considered. Potential hazards were identified and recommendations made for reducing the probability of fire or explosion and for reducing the severity of an incident should one occur. Accident expectancies were established and compared with goals set forth in DRCPM-PBM Memorandum 385-3.

The following three X-4 loader deficiencies were singled out:¹³

1. Compliance to the design goal of 1×10^{-5} accidents per facility hour for a class II-A hazard (critical). The report accident expectancy for the loader was estimated at 1.5×10^{-3} accidents per facility hour.

2. Use of copper alloy materials in sleeve bearings.

3. Exposure of operators to hazards more severe than a class IV hazard (negligible). The report indicates that there is some operator exposure to class III B (marginal) during operation.

A meeting was held with representatives of ARRADCOM (Safety, Human Factors, R&D, Production, etc.), Iowa AAP, and the Office of the Project Manager for Base Modernization relative to interpretation and resolution of the stated potential deficiencies. Each of the deficiencies was considered and evaluated with the following conclusions:

1. The attendees did not agree with this conclusion for several reasons. The component involved was the NOL-130 dispenser which had part of its assembly, a movable spoon, for measuring and dispensing the powder. The report states the cause of this problem as "a failure of set-screws on the spoon." This is contrary to field experience where there is no record of such an incident; many of these dispensers were in operation on single-tool loaders for many years. Also, time to replace this assembly was estimated at about 4 hours; on this basis, the system damage was minor rather than critical.¹⁴ Therefore, instead of II-A critical, the category was III-A marginal, and the goal of 1×10^{-3} was met. However, to further increase the security of subject spoon, a Locktite compatible with NOL-130 was recommended for application to the set screws. The barricade at Iowa AAP was tested for three times the maximum amount of NOL-130 which would be in this area. Should the dispenser blow, a conservative estimate to put the station back into working order would be about 4 hours.

2. Over the past few years, there has been disagreement over the use of components containing exposed copper or copper-bearing alloys in locations where there is a possibility of coating by lead azide dust. It is an important consideration because under laboratory conditions copper and lead azide synthesize to a compound which is more sensitive than lead azide. However, there doesn't appear to be a history of such an occurrence on detonator loading machines. To minimize any future possibilities of occurrences, brass fittings are being replaced on the X-4 loader, but sleeve bearings will remain as is for

¹³ Detailed data presented in "Safety Analysis of X-4 Multitooled Iowa Detonator Loader," ARLCD-CR-80022, Picatinny Arsenal, Dover, NJ, October 1980.

¹⁴ MPBMA OSM 385-1, pages 3 through 5.

several reasons: (1) there are no thin bearings of other materials void of copper which can replace these bearings, (2) thicker bearings would result in a very costly retrofit, (3) the bearing surfaces exposed to the dust are minimal since they are thin bearings, (4) a lacquer coating can be applied to exposed surfaces.

3. The third item unfortunately is a literal interpretation of a contract item which was misinformative (MPBMA OSM 385-1, pg 1-2, item c under 4). Policy states, "Operating and transient personnel will be exposed only to a negligible (Category IV) hazard level. (See Chapter 3)." Category IV (negligible) is defined as, "Conditions such that the failure mode occurrence will not result in injury, occupational illness, or system damage." Obviously, the policy statement cannot be adhered to in the situation of operating and transient personnel because there is always a possibility of injury to personnel who work close to or handle explosives. Therefore, the design goal would be to strive for a minimum of accidents and injuries, and classification would be category III-B (marginal). The summary in the ABL report shows a total III-B as 1.4×10^{-7} accidents per manhour which is satisfactory since this number is under the design goal of 1×10^{-6} .

The attendees agreed to several additional suggestions which would be of benefit to the X-4 multitooled loader:

- Replace all brass fittings with substitute materials such as aluminum, stainless steel, or plastic
- Apply a coating of lacquer to the exposed surface, where some copper bearing alloys exist and are too expensive to replace
- Consider using a sphere on casters for the detonator reject container
- Replace glass containers with plastic
- A suggestion to perhaps increase the spacing between detonators (or tooling) to prevent propagation was discounted because this would be very costly and experience to date shows this as a low risk area.

The results of these findings along with the safety analysis were officially forwarded to ARRCOM Safety and the load plants for their information and appropriate implementation.

System Hazard Analysis

A qualitative hazard analysis was performed on the modular detonator system production line by ITT Research Institute (ITRI), Chicago, IL. Because of a prior hazard analysis on the X-4 detonator loader and the inspection module, effort on these two modules was not repeated but rather the results made available to ITRI.

The overall layout of the modular detonator assembly system is presented in

figure 9. Following is an excerpt from the ITTRI system hazard analysis report¹⁵ which delineates the general sequence of operations around which the analysis was conducted:

System Operations. The X-4 loader receives empty aluminum cups, loads them with three explosive treatments (NOL-130, lead azide, and RDX), places an aluminum disc on the final RDX increment, and performs a 90-degree crimp closure. Because of the inherent design of the loader, operations on the detonators are performed in multiples of four at each station.

Upon exiting the loader, the detonators are placed in a 50-nest pallet (only 40 nests are used in each pallet; the outside two rows of nests are left empty) which is placed onto the pallet conveying equipment. The primary purpose and function of this conveying equipment is to transport assembled detonators produced by the loader to the cleaning station, the inspection station, and to the temporary packout station. This pallet conveyor has a variable speed drive with the capability of from 2.44 to 14.63 m/min (8 to 48 ft/min). The anticipated average production speed of the pallet conveyor is approximately 4 m/min (13 ft/min). It is also planned that the X-4 ejection speed of pallets will approximate the conveyor speed to insure a smooth transfer of full pallets so as not to jar detonators from their nests. Once on the conveyor, the pallet laden with detonators passes an optical sensor which checks for any detonators that may be propped above the top surface of the pallet. If such a condition is identified, an alarm is sounded and a gate remains closed to prevent this pallet from moving into position at the entrance to the cleaning station. If the alarm is not shut off by an operator, and the situation is not corrected within a reasonable time, then the loader should be automatically stopped. When a correctly loaded pallet passes the inspection station, it continues on the conveyor until it hits a second gate at the entrance to the cleaning station. At the proper signal from the controller, the pallet is removed from the continuously moving conveyor by a transfer unit into the cleaning chamber. In the chamber, a rotating brush driven by an electronic explosion-proof motor brushes the output (crimped) ends of each row of detonators from all loose explosive. Row by row (five detonators at a time), the detonators are raised up to a restraining wire and under the rotating brush. Each row is brushed going in and coming out of the vacuum chamber. The vacuum removes all loose explosives that might have been left at the output end of the detonator and collects it for proper disposal. The transfer unit motion at the cleaning station is perpendicular to the pallet conveyor.

After the cleaning operation, the pallet is moved back onto the pallet conveyor and transported into position at the in-feed indexing unit in preparation for removal of detonators (two at a time) into the first of four inspection

¹⁵ Swider, E. "Preliminary Hazard Analysis of Iowa AAP Automated LAP Line for M55 Detonator," Contractor Report ARLCD-CR-81049, ITT Research Institute, October 1982.

modules. Ten detonators are removed and inspected at each inspection module: the first ten at module A, the second at module B, the third at module C, and the fourth at module D. At the proper signal, two detonators are pneumatically removed from the pallet and conveyed in a plastic tube into the first inspection module. The present prototype line will only have one inspection module for testing and debugging.

In the final configuration, four inspection modules (each capable of inspecting detonators at a rate of 50/min) will be pressed into service to achieve the 150 detonators per minute design rate. On the prototype line, only the first 10 detonators are removed from the pallet and automatically inspected in the first inspection module (A), with the remaining 30 detonators being visually inspected by operators in the manual bypass inspection station located at the far end of the conveying equipment.

The inspection module inspects each detonator for flaws in the aluminum cup, bad and/or poor crimped ends, and foreign materials. The module consists of a line scan camera system for data acquisition and an analog computer as the data processor. A vacuum pulls the detonator against a rotating air motor, providing rotation for the inspection camera scan. These motors in the inspection module run continually. The scan results are compared to data stored in the micro-processor at which time the microprocessor determines the condition of the detonator and either accepts or rejects it. Upon completion of its scan, the rejected detonators are conveyed in a tube into a reject container inside the inspection module. However, the accepted detonators are pneumatically conveyed in a tube into a packing box which has been properly positioned by means of the packout indexing mechanism. Each box is indexed through a pattern until the entire box (50 detonators) is filled with accepted detonators, originating from consecutive pallets, having been inspected in the first module A. At a signal from the controller, the full box is moved from the packout mechanism onto the box conveyor, which runs parallel to the pallet conveyor, for transportation up to the transfer station. The box conveyor travels at the same speed as the pallet conveyor which is tentatively at approximately 4 m/min (13 ft/min).

When a full box of detonators reaches the transfer station located at the end of the box conveyor, and there are no oncoming empty and/or partially empty pallets on the pallet conveyor, the box is shuffled over onto the pallet conveyor. Because of this arrangement, the empty and/or partially empty pallets and filled boxes enter the last station riding the same conveyor.

At this final station in the system, operators will visually inspect for flaws in detonators that the prototype line cannot keep up with. These operators will slip the full boxes of detonators into covers and empty the pallets of all detonators. All empty pallets will be stacked in this final station and at proper intervals will be hand carried to the X-4 and inserted into the system. Also, the full boxes of detonators will be stacked and at proper intervals will be hand carried to temporary storage or to a location for application of lacquer.

Finally, one of the most important major components of any automatic system is the control console. The production line of interest has three control consoles. All operations involved with automatically loading detonators are programmed and controlled by the control console for the X-4. Also, all scan

data collection and decision making about acceptance and rejection of detonators is handled by a microprocessor controlling the inspection modules. All operations involved with the detonator handling system are supervised by a third microprocessor-based PLC. Eventually when the overall system has been proven out, a single integrated control system will most likely take over all control functions.

This is a short discussion of the physical makeup of the modular automated detonator production line. On this production line, empty detonator cups are filled with three different explosives; the cups are capped, crimped, and cleaned of excess explosive numerous times along the process; the assembled detonators inspected 100% for flaws, bad crimps, foreign material, and finally packaged for temporary storage. All this is processed by three control consoles and trained operators versed in automatic detonator assembly and explosive handling. Ultimately, this production line will produce detonators at a rate of 150 detonators per minute.

Based upon the preceding operations, a detailed preliminary system hazard analysis was conducted. Conclusions and recommendations are as follows:

Conclusions and Recommendations. Using a conservative approach, IITRI found hazards in this analysis that could lead to equipment damage and/or injury to personnel. From an overall viewpoint, there are certain conditions, events, and components that can play an important role in scenarios unacceptable to safe operation of the line. In combining potential hazards, the most credible hazards must be addressed.

The study of the equipment which comprises the production line shows that some accumulation of explosives is possible in the cleaning station chamber and vacuum duct. With the extremely sensitive primary explosives used in the detonator assemblies, mechanical action, shock, or electrical energy can produce the energy source to ignite the explosives. This potential hazard can be avoided by careful design or the cleaning chamber configuration to minimize accumulation of explosives. Also, a frequent periodic manual cleaning of the chamber and always shutting down the system if vacuum fails will greatly reduce this probable hazard. A signalling device should be installed at or near the exit from the cleaning station to sense when vacuum is not sufficient.

Another probable hazard was the possibility of an operator loading the X-4 with a pallet containing some detonators in their nests. This hazard, mostly due to human error, could be avoided by providing an automatic pallet handling means or developing procedures to insure that the pallets returning to the X-4 are empty. Strict procedures must also be developed and adhered to so as to assure that large accumulation of accepted or rejected detonators cannot occur in the packout station or in the reject bins.

Another potential hazard, that of spilling detonators, must not be allowed to occur, either by the equipment or the operators. If detonators are accidentally spilled or dropped, they must immediately be retrieved and properly disposed of.

The majority of the potential hazards on the line can be avoided through strict inspection schedule of the equipment, performing preventive maintenance, and in certain cases relying on the control consoles to automatically shut down the entire system when hazardous conditions develop.

Two of the most important components in the line are the conveyor belts. IITRI is especially concerned with the aspects of its manufacture, fabrication, material used, and application. It is recommended that the method used to splice and/or connect the belt ends results in a smooth, flexible, and durable joint. Under no circumstances should there be steps or protruding notches at the connections. Proper design and fabrication of the belts are essential.

IITRI is also concerned with the ease with which detonators in pallets can be partially jarred out of their nests. They assume a horizontal position in the nest and end up protruding above the top surface of the pallet. This condition is hazardous since it can cause jams at entrances to stations. IITRI recommends that the pallet be redesigned to eliminate this possibility.

The following actions are recommended to reduce the hazards and increase the safety of the line:

- Avoid striking or dropping detonators on the floor
- Provide means to warn if the safe number of detonators has been exceeded in reject buckets
- Provide overload sensors at the drive-thermal overloads
- Provide adjustable sensor mountings where necessary
- Redesign pallet to avoid interference when entering stations
- Provide mechanical stops to protect sensors
- Reconsider design for entrance to cleaning station to prevent wedging
- Consider complete automatic shutdown when alarm is not dealt with in predetermined time
- Limit maximum activation pressures to cylinders to minimize accelerations; consider flow controls
- Consider push-to-test equipment for check of lights for production equipment beyond this prototype
- Developed written procedures for the interim operation of the prototype line for adequacy and potential hazards
- Developed written procedures for the steady-state operation of the line and analyze for adequacy and potential hazards

- Developed written procedures for the routine maintenance and inspection of the equipment and analyze for adequacy and potential hazards
- Developed written procedures for an emergency shutdown and analyze for adequacy and potential hazards
- Make assembly area fireproof construction and free of combustible materials, good housekeeping is a must
- Control and limit the number of pallets and boxes of detonators in the packout area
- Electrically conduct and ground all conveyor belts
- Limit personnel to a minimum in the assembly area during detonator manufacture

Ultrasonic Weld Sealing

The current method for color coding and sealing M55 detonators is one of applying green lacquer to the crimped end and then passing the detonators through a forced hot air oven for drying. This process is labor intensive and requires a separate work area for application and drying. To develop a more efficient, quicker, more reproducible, and less labor intensive sealing method, it was decided that ultrasonic welding should be investigated.

A program was undertaken with Sonobond Corporation in West Chester, Pennsylvania, to determine the feasibility of hermetically sealing M55 detonators by means of an ultrasonic ring welder at a rate of 200 ppm. Ultrasonic ring welding was considered appropriate because it precluded external application of heat and was used for sealing other ordnance devices containing explosives, propellants, and other sensitive contents. The sealing bond is formed from the combined static and vibratory stresses induced between the two mating surfaces. The stresses disrupt the surface films and promote adhesion of the bare metals. In general, parts to be welded by this technique usually are configured so that there is an outward flange or shelf whereby the bottom surface can be rigidly supported by an anvil while the welding head is positioned and clamped on the top surface. Unfortunately, the detonator does not have this optimum configuration, and redesign would be an enormous and highly expensive task because of the configuration change necessitated in the vast number of end items. It was imperative that this investigation confine itself to the feasibility of ultrasonically sealing the detonator in its present configuration.

Initially, inert detonators were used to establish and optimize the welding parameters (e.g., power, clamping force, and weld time). The quality of the seals was determined by visual inspection and gross leak testing. The gross leak testing involved immersion of the samples in ethylene glycol in a dessicator that was evacuated at 25 to 28 inches of mercury. The welding and subsequent testing of the inert detonators indicated that a degree of effectiveness had been achieved with the seal. Based upon these results and the possibility that some

of the failures might be attributed to the lesser quality control requirements of the inert detonators, it was decided to proceed with welding live detonators.

Welds with the live detonators were evaluated by a more precise mass spectrometer helium leak detection technique. Two hundred detonators (50 of each group) were leak tested:

1. Ultrasonically welded closing disc with a chromate green protective finish (LS-79E-001-S418)
2. Crimped, bare, unwelded closing disc (KN-E-1)
3. Ultrasonically welded bare closing disc (KN-E-1)
4. Production with a standard crimped closing disc and lacquer finish (LS-DZ-4199)

Each group was removed from its protective packing and placed on a special aluminum chassis so that the seal of each detonator was exposed to atmosphere. Each chassis was then placed in a pressure vessel containing only one group of 50 detonators.

The pressure vessel was then evacuated to 5000 microns vacuum using a 5 ft³/min high vacuum pump and thermister vacuum gage. Utilizing a special isolation manifold, the pressure vessel was then repressurized to 15 psi helium \pm 1 psi. This pressure was held for 4 hours \pm 1/10 hour.

At the end of the 4 hours, the helium gas was vented to exterior atmosphere to avoid contaminating the atmosphere near the leak detector. Utilizing the special isolation manifold, the pressure vessel was flushed with plain air at 30 psi for 30 seconds. At this point the vessel was opened and the chassis containing the detonators was removed for leak testing.

Each detonator was individually tested for helium leakage in the mass spectrometer. The recorded leak rates were plotted as a function of time after removal from the pressure vessel (fig. 18). Both types of ultrasonically welded detonators and the units that had been crimped over plain discs without welding showed approximately equivalent leak rates. No leakage at all was detected with any of the standard detonators (i.e., crimped and lacquered).

Results of standard lot acceptance waterproofness tests conducted at Lone Star Army Ammunition Plant on the same detonator lots confirmed the preceding helium leak tests. The results at Lone Star AAP were as follows:

<u>Test</u>	<u>Passed (%)</u>
100 lacquered standard	96
100 clear disc-unwelded	1
100 clear disc welded	5
100 chromate disc-welded	36

Details of the investigation, along with descriptions of the welding equipment, the hazard analysis, and the helium leak detector are available¹⁶. Basic conclusions and recommendations are as follows:

Conclusions and Recommendations. With the M55 stab detonator in its existing geometry, reproducibly leaktight seals were not obtained by ultrasonic ring welding. Both inert-loaded and explosive-loaded detonators showed unacceptable leakage rates.

It is recommended that further consideration be given to the possibility of revising the cup geometry to provide an outward flange to which a cover disc can be ultrasonically ring welded, since this technique has been demonstrated to provide the desired results. Subsequent redrawing of the flange to a cylindrical geometry is feasible.

Metering Accuracy

Detonator loaders employ two basic dispensing system for lead azide (Iowa Ball and the Lone Star Chamlee). Both are essentially volumetric devices where the powder flows into a cavity of a known volume and is then dumped into a detonator cup. In support of the development of the modular detonator system as well as future system developments, a program was established to conduct a comparative analysis of the relative accuracy and precision of the Iowa Ball and Chamlee metering devices. Each metering device was run for 5 hours with special-purpose lead azide and an additional 5 hours with RD1333 lead azide at a metering rate of 30 increments per minute. The test was conducted so that both individual and cumulative average weighings were made. Specific details as well as photographs of the dispensers and test equipment are available in Volume II, appendix E. A summary of the results, conclusions, and recommendations are shown in table 4.

The Chamlee can be adjusted for amount delivered remotely without stopping and shows only random deviation from the mean. The Ball loader has to be stopped to adjust the quantity delivered and shows a progressive increase in quantity delivered because of the buildup of a film of lead. This film is removed in production at the end of the 8-hour shift, and the amount delivered adjusted progressively throughout the shift. The film noticeably altered the output of the Ball loader during the first 2 or 3 hours of these tests. In fact, it caused the sealing gasket to lift up and allowed small quantities of azide to be dispensed on the back stroke. It was concluded that:

¹⁶ Krause, Philip C, Sonobond Corporation and Monteleone, Paul, ARDEC, "Ultrasonic Weld Sealing of M55 Stab Detonators," Technical Report ARLCD-TR-80051, ARRADCOM, Dover, NJ, January 1981.

1. Test results showed no significant differences between the two techniques as far as accuracy is concerned.

2. Ball results in successive increases in increment weight with time and Chamlee results in a random spread with time.

In view of the insignificant differences in performance (spread and deviation) between the two techniques, the advantages offered by the Chamlee with respect to "on-the-fly" adjustment, lower blow rate, and no requirement for frequent cleaning would appear to make the Chamlee the preferred technique.

Automated Detonator Seal and Dry System

Concept work on experimental detonator sealing or lacquer application equipment began with the intent of automatically applying lacquer in a manner similar to the traditional dip-pin method in which a flat-tipped pin of a diameter approximately equal to the exposed foil of any given size detonator is dipped in a tray or lacquer and brought nearly into contact with the crimped detonator foil. Physical contact between the pin and detonator is not made, but the pin is placed close enough to transfer the drop to the detonator foil surface. In practice, a matrix of pins is formed to match the orientation of the detonator packing tray. In the case of the M55 detonator, this is a 5 x 10 array.

Specifically, the seal and dry system was to apply lacquer and dry detonators at the rate of 400 units per minute in support of two X-4 Iowa detonator loaders. For the prototype, however, only one of two lacquer application modules was to have been provided to support one X-4 loader, but was to have been provided with a drying system sufficient to dry 400 detonators per minute.

The approach to lacquer dispensing used for the initial investigation was an adjustable time and stroke pinch tube system with a pressurized reservoir instead of a revision to the traditionally dip-pin concept. The advantages in using the pressure dispenser appeared to be precise sizing of the lacquer droplet, elimination of the evaporation of the lacquer volatile material through use of the pressurized reservoir, and adaptability to automation. In support of this approach, a Tridak Model 280J dispense system was ordered and received. This was a single-needle system with reservoir and controller and was obtained for the purpose of a lab scale test of that type of dispenser.

The dispenser in question works through the precise pinching of a plastic (disposable) tube by a micrometer adjusted metering head. The stroke of the pinch valve is determined through the micrometer setting. The duration of the opening is controlled through the setting of an electronic controller. This controller adjusts air pressure on the reservoir from 0 to 30 psig, sets dispensing duration from 0 to 2.0 sec over a stepless range, and sets the dispensing mode between off, automatic, and manual. A wide variety of standardized syringe type needles can be applied to vary the size of the dispense dot.

A copy of the test report describing the initial performance tests with the single-shot dispenser is included in Volume II, appendix F. The performance test

involved letting the single-shot dispenser operate continuously for 48 hours. It was initially set to cycle every 10 seconds. At that rate, a 50-shot dispenser in a production environment would apply lacquer to approximately 100,000 detonators per 8-hour shift. Test drops were collected every 30 minutes to determine the consistency of the drop size. There were only minor fluctuations observed over the initial 6-hour period. The dispenser was allowed to cycle overnight unattended. Some leakage from a loose fitting occurred overnight. The drop size increased with respect to the previous day's data because the hose was worn and the protective, or tube support, housing surrounding the hose was worn through. The hose and housing were replaced and the dispenser allowed to continue cycling. During a shutdown to simulate a lunch break, lacquer dried in the needle clogging and preventing its operation. The dried lacquer was easily removed by switching to the manual mode and increasing reservoir pressure. The dispenser again cycled overnight but with a smaller needle. During that time, the needle clogged but was cleaned out the next morning by the previous method. Again the protective housing was worn through. However, the dispenser appeared to show promise. After completion of the initial test, a Teflon pinch tube was obtained from the vendor. This tube withstood approximately 52,000 cycles and was still intact. It was believed that this change would solve the tube wear problem. The single-shot test unit which had been obtained through a lease arrangement was returned, and plans were made to procure a full size 50-shot production dispenser.

The 50-shot dispenser (fig. 19) is very similar in nature to the single-shot unit with one tube from the reservoir being replaced with 50 tubes. The single-pinchoff valve is replaced with a multiple-pinchoff plate which is activated by a single-pneumatic actuator. A single-micrometer adjustment is supplied for the pinch plate. The dispenser manufacturer is responsible for flow testing and balancing of the 50 individual dispensers. The electronic control for the 50-shot unit was the same as for the single-shot unit. Several photographs of the 50-shot unit are included in appendix F. During testing of the system both water and various mixtures of lacquer and thinner were tried. While a mixture of five parts lacquer to four parts thinner appeared to work the best, results of testing were generally unsatisfactory. The system, as received, produced drops which were too large. This occurred with all adjustments intended to regulate drop size adjusted as far down as possible. The only way to reduce drop size further would be to reduce the needle and tube size further. Doing this would worsen an already serious problem of needle clogging. Although all materials used in the system were filtered, clogging was still encountered. Cleanup of the small tubes and needles also presented difficulties. Passing thinner through the system was not sufficient to do the job. It became apparent that the system being tested, while well suited for dispensing of individual increments of certain types of liquids such as pharmaceuticals in an ultraclean environment, is not suited for multiple dispensing to the degree required, with the materials required, in an industrial environment. It was concluded at the end of testing that the unit would be marginal at best in operation, requiring exacting setup and a high degree of cleanliness and care in cleanup. Efforts in testing the 50-shot dispenser were therefore terminated.

Improved Aspirate System

Cleaning of the detonator loading machine tooling and tooling dial has traditionally been accomplished with a vacuum system whose source is a compressed air powered ejector. Unlike other types of vacuum pumps, the ejector has been particularly suited to pumping of fluids contaminated with explosive due to its complete lack of moving parts. The ejector is essentially a venturi tube through which a working fluid is passed under pressure. The fluid located in the suction chamber at the venturi discharge is entrained by the high velocity stream of the working fluid creating a low pressure condition with the fluid in the suction chamber flowing toward the ejector discharge. The suction created is then used as the vacuum source for cleaning. A water trap filter is then used upstream from the ejector to filter out as much of the explosive dust as possible. Any explosive material getting through the filter would wind up in the high velocity airstream and be discharged. The problem with the ejector is its low efficiency. Large quantities of working fluid are required to produce the necessary low pressure (vacuum) level and rate of flow.

An analysis of the operating costs of various methods of aspirating explosive dust as well as providing a vacuum source for vacuum drying of initiating explosives was prepared (volume II, app G).

Comparing the cost of providing a vacuum source with compressed air ejectors to using a vacuum pump for 30 single-tooled Iowa detonator loaders and 52 initiating power drying systems results in some very surprising results. The total operating cost of compressed air ejectors was \$38 per hour while the cost of operating a vacuum pump system was \$0.90 per hour.¹⁷ At the time this analysis was made, the operation of the vacuum pump system was an unknown; therefore, some operational costs were not included. However, it is believed the cost difference was still substantial.

Several types of vacuum pumps were considered. Both rotary vane and piston pumps would provide adequate volume and vacuum level to meet the demands of loader aspiration. The problem with these is the metal-to-metal contact required at the sealing surface. It would be absolutely essential that initiating powder would not enter this type of pump, requiring the use of an elaborate filter system which would have to be much more efficient than the standard water-bottle type filter used with the air educators.

Iowa AAP proposed the use of a liquid ring vacuum pump (fig. 20) as a source of vacuum for aspiration. Unlike other vacuum pumps, this type has not metal-to-metal contact and, in fact, has only one moving part which is a balanced rotor. A rotating liquid or compressant performs the sealing function replacing all other types of seals which would involve metal-to-metal contact. The liquid compressant nearly fills then partially empties each rotor chamber during each revolution of the rotor which creates the low pressure or vacuum condition. The

¹⁷ All money in this report is in FY 77 dollars.

rotor axis is offset with respect to the pump housing axis which creates a variation in rotor chamber volume as the rotor rotates. The compressant only partially fills the pump housing. During the angle of rotation in which the rotor chamber volume is increasing, centrifugal force displaces the compressant to the outside portion of the rotor chamber which evacuates the inside portion creating a suction drawing the gas through inlet ports into the rotor chamber. As rotation continues, the rotor chamber volume decreases which moves the compressant inward, compressing the gas in the rotor chamber. As the rotor moves into the discharge sector, the compressed gas expands and escapes through the discharge ports.

Two manufacturers of liquid ring pumps provided information [Nash Engineering Co. and Sieman and Hirsch (SiH)]. The pumps appeared to be identical in design with slightly varying efficiencies. Both pumps had safely handled such hazardous materials as ethanol, methanol, and isopropal alcohols as well as acetylene, helium, hydrogen, gasoline vapors, methane, and propane.

Since it was assumed that some initiating explosive would enter the vacuum pump regardless of the filter chosen, it was decided to use a desensitizing agent as the compressant, and a dilute sodium hydroxide solution was selected. Therefore, any explosive reaching the pump would be neutralized. The compressant would then be treated in the industrial waste treatment system.

The single-tooled Iowa detonator loader required six water-filled filter bottles; the X-4 Iowa detonator loader requires 18. While these filters worked well, the numbers of them in a full scale detonator facility running at mobilization rates would involve significant numbers of operators for changing, transporting, and cleaning of filter bottles. The Line 4A detonator facility at the Iowa AAP would require 180 bottles be changed, transported, and cleaned every 4 hours while operating at mobilization rates. To reduce this labor intensive effort, a central filter system was investigated. The purpose of the centralized configuration was to replace the multiplicity of bottles. A system of three 15-gal. stainless steel milk cans in series, filled with desensitizing solution, and mounted on a cart was considered. This system would provide a three-stage filter in which the first stage would collect most of the aspirated initiating explosive from the vacuum airstream. This system of three cans would replace the 18 water bottles needed for the X-4 Iowa detonator loader.

While considering this filter concept, the feasibility of constructing a filter system consisting of a three cell rectangular steel vessel with interconnecting steel pipes was conceived, which in principle would be identical to the milk can arrangement but with several advantages. It could carry a greater volume of desensitizing solution in the first chamber than would be possible in a milk can, which would reduce the frequency of dumping and cleaning. The tank would be more stable than a series of milk cans, and with the installation of quick-dump diaphragm valves, would be much simpler and physically easier to empty than the milk cans which would require being picked up and turned over to empty. Therefore, operator would have less direct exposure to the sodium hydroxide solution. The internal cells would be connected with permanent piping to reduce the number of connections for installation.

An order was placed with Compressor Engineering Co. for the liquid ring vacuum pump system that included the vacuum pump, separator/silencer, sodium hydroxide replenishment tank, compressant pressure pump, heat exchanger, heat sink, cooling water pump, as well as miscellaneous piping, fittings, and valves. A photograph of the pump system at the time of installation is shown in figure 21. The filter unit, although an integral part of the system, was procured separately.

Specifications for the vacuum pump system as procured from Compressor Engineering Co. are as follows:

Inlet volume	260 ft ³ /min
Vacuum	8 in. Hg
Pump speed	1170 r/min
Pump BHP	17 hp
Motor size	20 hp, 208 V, 3-phase
Motor speed	1170 r/min
Pump type	Nash, single stage, positive displacement, nonpulsating, liquid sealed, rotary vacuum pump; all cast iron construction.
Reservoir	280-gallon, visual level indicator, drain valve, liquid level control
Compressant pump	Worthington, Model D511, centrifugal pump, all stainless steel construction driven by 2 hp, 208 V, 3-phase motor
Heat exchanger	Basco Model 5025-54, stainless steel tubes, steel shell
Silencer-separator	Three-inch Burgess-Manning WSDA

Prior to explosives being introduced in the vacuum pump system, a test with inert material ($PbSO_4$) was performed with water as the compressant (app G).

Although neither a full scale production proveout nor demonstration test was conducted on this task, limited testing accomplished with live explosive demonstrated that the system, although needing some improvement, was workable and demonstrated the potential in energy savings.

The vacuum pipe size from the pump system to the portable filter was a 2-inch outer diameter, 16-gage tube. This vacuum supply line needed to be increased in size due to excessive pressure drop which in a low differential pressure system can be serious. No records of pressure drop during testing are available; however, performance was affected.

In spite of the recognized advantages of the three-cell tank used as a portable filter, it was decided that for ease of liquid changing as well as cleaning, three separate filter vessels as originally proposed would be more advantageous than the three-cell tank. The internal piping arrangement of the three-cell tank lent itself to sealing problems, although external hoses between vessels would be harder to handle, they could be sealed easier.

The fact that testing of this prototype vacuum system was not completed prior to the compressors being bought by the Corps of Engineers Construction Contractor for the Line 4A detonator expansion project (Project No. 5782765) resulted in the liquid ring pump system not being considered for use on the Line 4A detonator project. However, although not used in Line 4A, the basic design has progressed to the point that it should be given consideration for future modernization projects.

Explosive Resupply

With the completion of the detonator backline and frontline modernization projects, the handling of dry initiating explosive has been reduced to the point that personnel exposure only occurs during resupply of the detonator loading machines. At that time, the operator reaches into the frontline storage barricade, withdraws a small cup containing 1 to 2 oz of initiating explosive, carries it to the loading dispensing barricades. The barricades have two doors (an inner and an outer) which allows placement in the barricade without exposure of the operator to the actual dispensing operation which can continue during cup placement. The purpose of this effort was to eliminate the handling of the powder cup entirely, completely eliminating all exposure to dry initiating powder. The intent was to couple the manual explosive transport vehicle (METV) which transports up to 20 oz of powder in 2-oz. cups from the backline process barricades to the frontline storage barricades, directly to the dispensing barricades on the loader. The initial concept involved placing a tunnel on the dispensing barricade with some type of internal tray transfer system. The METV would clamp to the tunnel as it now clamps to the existing front and backline barricades. The tray transfer system would have been similar to that used on the current frontline barricade, the tunnel being required due to lack of space in the dispensing barricade.

This effort did not get through the concept stage and no formal drawings or sketches are available. Serious concern arose regarding the ability of the barricade and tunnel arrangement to withstand the effects of an accidental detonation of the quantities of powder which would be present (approx 10oz). The mechanisms involved would have had to be very complex, especially if more than one cup of explosive was involved. Also, a problem existed in the comparative heights between the highest dispensing barricade and the METV access door. The barricade door is 57 inches high while the METV is 27 inches; therefore, the METV or its contents would have to be raised 30 inches. Because of the complexities involved and the risk of failure, it was decided that design and equipment funds could better be spent on other project efforts; therefore, the effort was terminated.

RESULTS

Feasibility and investigatory efforts were conducted on a detonator production system with a design rate objective of 800 to 1200 detonators per

minute. Following is a summary of the basic technology survey and experimental evaluation phase results:

- Feasibility was established for handling, feeding, and compacting primary explosives (NOL-130 primer mix, lead azide) and RDX in M55 detonator cups at rates approximating 800 to 1200 ppm

- Feasibility was established for disc insertion, crimping, and sealing M55 detonators at rates approximating 800 to 1200 ppm

- Feasibility was established for semi-automated M55 detonator packing system design

- Seven experimental bench models were designed and tested with satisfactory results:

- FMC loading model

- MRC loading model

- Bulova loading model

- FMC packing model

- MRC disc insertion model

- MRC sealing model

- MRC crimping model

- Hazard analyses were conducted on design concept models

- Basic design features were established for a line capable of loading 800 to 1200 detonators per minute.

A concept for a prototype detonator production line capable of manufacturing and inspecting M55 detonators, from the feeding of metal cups through the drying of sealing lacquer at a design rate of 800 to 1200 detonators per minute, was developed. Design goals of the system are:

- 800 to 1200 parts per minute

- Full automation from feeding cups through packing of cartons, remainder of line mechanized

- 10 year life

- Interchangeable tooling and machines

- Quick change machines, 4 hours maximum

- Maximum of 5 men to run individual line

- 100% automated inspection
- Preventive maintenance, 2 hour max/day
- Improved powder metering accuracy and precision ($\pm 5\%$)
- One intersubmodule storage (buffering) specified and intrasubmodule storage to be analyzed during design and demonstration tests
- Duty cycle, 16-hrs shift/day

A pilot line was designed that is capable of demonstrating the principles of the preceding prototype detonator production line concept while operating at a reduced output of 100 detonators per minute. Although the pilot line output rate is 100 detonators per minute, each individual process in the pilot line is designed to operate at an actual speed of 1200 detonators per minute (i.e., the 1200 detonators per minute prototype has a multiple number of tools performing the same operation demonstrated on the pilot line). Certain design areas which were deemed to be high risk (e.g., cup feeding/singulation, and powder dispensing) were further bench modeled and tested prior to their incorporation in the pilot line design and prototype concept.

In support of proposed increased rate detonator equipment designs, characterization studies were conducted on existing equipment and proposed concepts to determine the significance of the environmental forces created by the new designs on detonator manufacture. Principle areas of concern were consolidation velocities, use of powdered RDX, and effects of centrifugal forces on detonator powders. Results of the investigation follows:

- Approach velocities of the consolidation ram for the proposed increased rate design is less severe than the present detonator production equipment. Tests on detonators loaded at the proposed extreme ram consolidation speeds yielded acceptable results.
- The effect of centrifugal force on the loose explosive/powders did not pose a problem in uniform consolidation.
- The effect of loose RDX as opposed to the prepelletized version had no effect on detonator functioning.
- One additional spinoff investigated under this task was that of the general correlation between the standard detonator ball drop acceptance test and two new potential inspection techniques which could be more readily applied to increased rate production (i.e., particle velocity and gamma ray densitometer techniques). Of the two, it was concluded that based upon the limited testing conducted, that the particle velocity technique offered general correlation while the densitometer technique would require more intensive testing.

In an effort to further reduce manufacturing time, an investigation was conducted into existing lacquers, new lacquers, and various thinners to find a method to reduce drying time of the lacquer sealant applied to detonators. The

result of the investigation was that general purpose nitrocellulose lacquers will meet a drying time of less than 1 minute when reduced with acetone. However, with the very fast drying times, it became apparent that the present open-tray type systems would have to be replaced with a closed system.

Due to changes in payback philosophy, estimated high costs for the increased rate prototype equipment and the desire for a less complex approach, it was deemed advisable by higher headquarters to redirect the single 800 to 1200 part per minute pilot/prototype efforts to a 150 multimodule approach using the basic Iowa multitooled loader along with ancillary equipment and associated improvements.

A number of successful improvements were made to the basic multitooled detonator loader to improve reliability, availability, and maintainability. The improvements made are as follows:

- Redesign input-output cards to take advantage of a newer card design
- Redesign powder barricades to allow for replenishment of both lead azide and NOL-130 during machine operation
- Design alpha numeric machine fault indicators for the control panel
- Redesign dial to allow for access after the primer consolidation station
- Redesign air-amplifier cabinet to allow for installation of air regulators
- Design battery memory backup to avoid memory loss during power outage
- Redesign brake mechanism for powder guide transfer mechanism
- Redesign cup-feeder entrapment to eliminate cup-transfer problems
- Redesign RDX feeder to increase the capacity for RDX pellets

A prototype cleaning station using a rotating brush and vacuum was designed and developed for cleaning M55 detonators (in pallets) as they emerged from the multitooled loader.

A prototype material handling system was designed and developed for conveying detonators (in pallets) from the loader through the cleaning and inspection station to the packout area.

An investigation into ultrasonic sealing resulted in the fact that the use of ultrasonic welding as a method for sealing the M55 detonator requires a physical change to the detonator configuration (i.e., the M55 cannot be ultrasonically sealed in its present configuration). Following is a summary of the standard lot acceptance waterproofness tests at Lone Star AAP comparing the standard and welded detonators under test:

<u>Tests</u>	<u>Passed (%)</u>
100 standard detonators with lacquer	96
100 detonators - no lacquer	11
100 detonators - ultrasonic weld, clear disc	9
100 detonators - ultrasonic weld, chromate disc	36

An investigation into a module for 100% automated inspection of critical, major, and minor defects was terminated because of technical difficulties. A lessons learned report isolated areas of difficulty and recommended actions for future endeavors was completed on this effort. Information and documentation relative to the pneumatic transport and propagation characteristics of detonators is also included.

An investigation was conducted into the development of an automated lacquer dispensor which could apply lacquer to 50 detonators at one time in a 5 x 10 matrix. The results of the efforts with a 50-unit TRIDAK type dispensor indicated that the system is not suited for multiple dispensing with the materials required in a load plant environment.

A prototype aspirate system using a liquid ring vacuum pump was developed. This system, through the use of the liquid ring vacuum pump as opposed to the present venturi system, provides the potential for a significant reduction in energy consumption. Because of time constraints, this system was not included in the present Line 4A; however, it is available for consideration in future upgrading.

Detonator loaders employ two basic volumetric dispensing systems (Ball and Chamlee). To facilitate both present and future loader designs, a comparative analysis of the accuracy and precision of both was conducted. Although the differences in spread and deviation between the two appeared insignificant in performance, the advantages offered by the Chamlee with respect to on-the-fly adjustment, lower blow rate, and no requirement for frequent cleaning would appear to make the Chamlee the preferred technique.

Through efforts expended on this program, the need arose for alternate means for conducting output, chemical analysis, and waterproofness tests which can be conducted more quickly and will provide more meaningful data. These efforts have been pursued under separate programs.

An improved baseline of data for both RAM considerations and equipment design parameters resulted from this program (e.g., punch consolidation velocities, lacquer drying time parameters, etc.).

CONCLUSIONS AND RECOMMENDATIONS

Based on the successful results of the planned improvements to the prototype multitooled loader and a series of reliability/acceptance tests, six additional loaders (150 detonators/min) were procured for the modernization of Line 4A at Iowa Army Ammunition Plant.

Should the requirements and payback philosophy revert to mobilization requirements, a production system capable of loading, assembling, and packing M55 detonators at a rate of 800 to 1200 parts per minute (ppM) is considered feasible.

At rates of 800 to 1200 ppm or 150 ppm, inspection for critical, major, and minor defects remains a major task. There apparently are electro-optical systems which approach the required accuracy capabilities for this effort; however, the method of detonator presentation and handling during the required inspection interval remains a problem. A second problem centers about the ability of the equipment to reliably differentiate between explosives on the detonator surface and graphite on the same surface. One final consideration is that of reliably characterizing defects such as workmanship. In keeping with the preceding, future inspection efforts should center heavily on studies and bench modeling of the inspection technology along with the mechanism for handling the detonator during the inspection interval. For example, if an electro-optical framing camera approach were to be used, the camera/electronics portion plus the method for rotating the detonator through the camera's field of view should be thoroughly bench modeled and proven before proceeding with the remainder of the system.

Based on the tests with ultrasonic welding, lacquer remains the prime contender for sealing the M55 detonator in its present configuration. The one exception to this is through the use of a hot-melt adhesive for detonator sealing. Limited efforts indicate that this is a viable sealing technique, and future efforts should continue around this technique.

Future detonator assembly equipment programs should particularly review and use the information derived from this program's efforts (e.g., consolidation profiles of standard loaders, characterization data, accuracy and precision of powder dispensors (Ball versus Chamlee), cleaning and material handling designs, liquid ring vacuum pump aspirate system, and lacquer investigation results.

Table 1. Jones/Iowa loader station comparison

<u>Feature</u>	<u>Jones Loader</u>		<u>Iowa Loader</u>	
<u>Feature</u>	<u>Station</u>	<u>Operation</u>	<u>Station</u>	<u>Operation</u>
Stations		24		24
Memory		Geneva drive electro-mechanical chain drive for powder increments		For powder increments, Pin type
Diameter		52"		60"
Speed (rpm)		1 2/3		
Strokes/minute		38-42		
Lead azide (wt)		51-60 mg.		
NOL (wt)		15-19 mg.		
Total unit (wt)		96-111 mg.		
Powder height adjustment		Station 17		
Cup feed	1	Cup reservoir-tube feed	1	Feed, orient, and seat cups
Inspect/detect	2	Inspect absence of cup, malformed cup, inverted cup, mechanical-stops machine	2	Checks for inverted cup, stop machine
Powder guide (install)	3	Belt fed, self inspect, mechanical-stop machine	3	Lifted from rest, seated on cup in dial
Malfunction switch	4	Open station	4	Sensing switch inspects for malfunction of station 3 stops machine
Meter and dispense NOL	5	Cargill scooper, bowl rotates 15-degrees/stroke, bowl holds about 20-min supply of powder	5	Automatic scooper
Memory actuator	6	Open station	6	Actuates memory pin valve to reset pins

Table 1. (cont)

<u>Feature</u>	<u>Jones Loader</u>		<u>Iowa Loader</u>	
	<u>Station</u>	<u>Operation</u>	<u>Station</u>	<u>Operation</u>
NOL consolidation	7	70 K psi 0.018 in. high, self-inspect, activities memory-mechanical	7	Press to pre- determined height and pressure, self- inspect, acti- vates memory
Sense and clean	-	---	8	Sensing switch overrules sta- tion 9
Meter and dispense lead azide	8	Chamlee ball--air activated	9	Meter and dis- pense lead azide
Signal	9	Open station	10	Switch negates counter of sta- tion 11
Lead azide consolidation	10	10 K psi, total height 0.082 in., self-inspect activities memory, mechanical	11	Press to pre- determined height and pressure, self-inspect, actuates memory
Alignment	11	Open station		
	12	Provides fixed reference point, prevents free coasting and backlash		
	13	Open station		
	14	Open station		
Powder guide (pick up)	15	Three pickup jaws liftguide to ramp lead to belt, return over dial to station 3	12	Pickup powder guides and place on rest
Malfunction sensor			13	Inspect for malfunction of guide remover stop machine

Table 1. (cont)

<u>Feature</u>	<u>Jones Loader</u>		<u>Iowa Loader</u>	
	<u>Station</u>	<u>Operation</u>	<u>Station</u>	<u>Operation</u>
RDX pellet feed	16	Pellets in tube magazines slide pick and place with punch insertion	14	Feed pellets of RDX and place in cup
Signal			15	Switch negates counter of station 16
RDX consolidation	17	15 psi, height 0.131 in. ± 0.004 , no monitor for height	16	Consolidate RDX, adjustable stop
Closure punch	18	Punch and die with spring loaded pin stripper rod	18	Dispense foil, blanks and places disc in cup, rolls up used foil strip
Clean	19	Open station	19	Aspirate to clean excess powder from foil, cup
Crimp 45 deg	20	Die form	20	Crimp 45 deg using crimping tool
Clean	21	Vacuum	21	Aspirate station area only
Crimp 90 deg	22	Fixed die, final length control	22	90 deg crimp, same as for 45 deg
Ejector	23	Memory readout, eject to sorting chute	23	Ejected items moved to dial for removal of rejects on signal from memory system
Clean	24	Vacuum empty die assembly		Aspirate station and powder guide

Table 2. X4 Iowa loader 40-hour test

<u>Date</u>	<u>Production rate</u>			<u>Rejection rate</u>
5-11-81	33,112	total		
	1,784	rejects		
	<u>31,328</u>	accept		5.3%
5-12-81	36,368	total		
	1,779	rejects		
	<u>34,589</u>	accept		4.8%
5-13-81	22,612	total		
	1,417	rejects		
	<u>21,195</u>	accept		6.2%
5-14-81	34,724	total		
	2,716	rejects		
	<u>32,008</u>	accept		7.8%
5-15-81	39,372	total		
	2,983	rejects		
	<u>36,389</u>	accept		7.5%
166,188	total produced			
10,679	total rejects			
<u>155,509</u>	total accept			6.4 average

33,237 total production average
31,101 total accept average

Table 3. M55 Inspections

<u>Defects</u>	<u>Definition</u>	<u>Present inspection</u>	<u>Notes</u>	<u>Reference</u>
Caked explosive on exterior	Discoloration and particles distinguished by human eye	100% inspection, fast scan and wiping of all detonators as they are removed from loader	Particle of 0.010 in. diameter to be distinguished	MIL-D-14978A
Exposed explosive (due to missing disc or tear on metal cup	Color other than metallic or green	100% inspection as detonators are removed from loader	Discoloration of 0.010 in. width to be detected	MIL-D-14978A
Outer diameter	0.147 in. - 0.002 in.	Sampling procedure; gauge measurement		Dwg 8798331
Length (with lacquer	0.143 in. - 0.006 in.	Sampling procedure; gauge measurement	Inspection prior to lacquer to be 0.141 in. - 0.002 in.	Dwg 8798331
Crimp 360 deg	Crimp must be continuous through 36 deg	100% visual scan	Crimped metal 0.015 in from edge to outer diameter	Dwg 8798331
Disc wrinkled or folded	Individual discrimination of wrinkle; folded disc exposes explosive	100% scan as detonators are trayed		Dwg 8798331

Table 3. (cont.)

<u>Defects</u>	<u>Definition</u>	<u>Present inspection</u>	<u>Notes</u>	<u>Reference</u>
Crimp radius maximum	0.015R	Sampling procedure; comparator device		Dug 8798331
Distortion	Individual judgment	Continuous visual inspection while doing other inspections	Not totally quantifiable	MIL-D-14978A
Workmanship	Example is a crimped end not distinguishable; subjective discrimination of individual	Continuous visual observation in conjunction with all other inspections	Not quantifiable and automation not readily implemented	MIL-D-14978A

Table 4. Metering comparison

<u>Loader</u>	<u>Type</u>	Individual samples, mg			Cumulative samples, mg		
		<u>Mean</u>	<u>Deviation</u>	<u>Spread</u>	<u>Mean</u>	<u>Deviation</u>	<u>Spread</u>
Chamlee	Spec. Pur. (Lot JA 4-61)	50.4	1.81	8.8	49.7	1.19	4.3
Chamlee	RD1333 (lot OMC 2-2)	50.0	2.42	8.0	50.2	1.68	7.1
Ball	Spec. Pur. (Lot JA 4-61)	54.9	2.56	10.2	54.6	2.53	12.4
Ball	RD1333	52.7	1.59	8.5	53.3	0.88	3.9

A. CHARGE, UPPER, PRIMER MIX, NOL 130 -
(15mg Approx) (.23 Grains)

- (1) Lead Styphnate, Basic, Type II,
SPEC MIL-L-16355 (40% By Weight \pm 2%)
Alternative is Normal Lead Styphnate
SPEC MIL-L-757
- (2) Lead Azide, Type 1, SPEC MIL-L-3055
(20% By Weight \pm 2%)
- (3) Tetraacene, SPEC MIL-T-3055
(5% By Weight \pm .5%)
- (4) Barium Nitrate, Class 1, SPEC MIL-B-162
(20% By Weight \pm 1.5%)
- (5) Antimony Sulfide, Class 5, SPEC MIL-A-159
(15% By Weight \pm 1.5%)

CONSOLIDATION PRESSURE 70,000 psi APPROX.

B. CHARGE, INTERMEDIATE, LEAD AZIDE
(51mg Approx) (.79 Grains)

- (1) RD 1333 Lead Azide SPEC MIL-L-46225
- (2) Alternative Lead Azide -
Special Purpose MIL-L-14758

CONSOLIDATION PRESSURE 10,000 psi APPROX.

C. CHARGE, LOWER, RDX -
(19mg Approx) (.29 Grains)

- (1) RDX, Type 1, SPEC MIL-P-45486

CONSOLIDATION PRESSURE 15,000 psi APPROX.

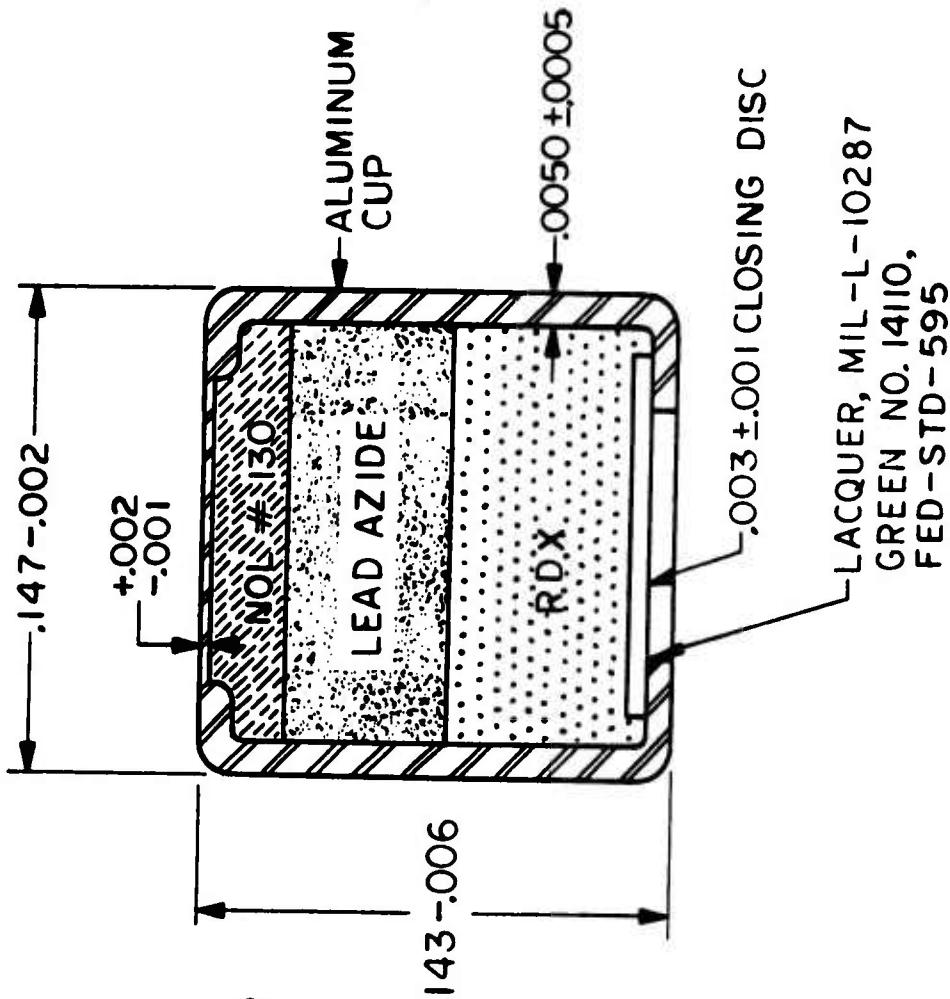
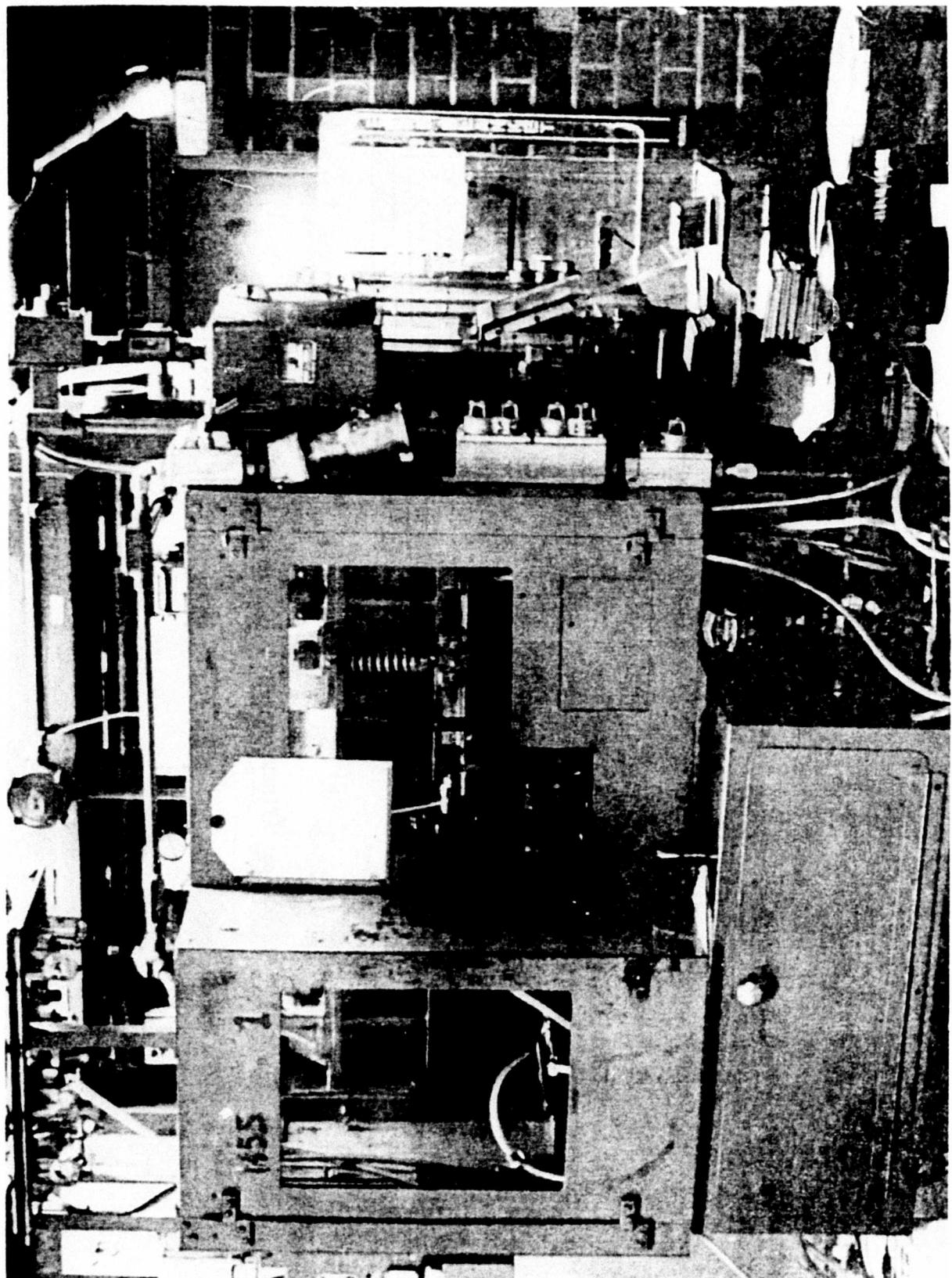


Figure 1. M55 stab detonator

LACQUER, MIL-L-10287
GREEN NO. 14110,
FED-STD-595

Figure 2. Jones loader



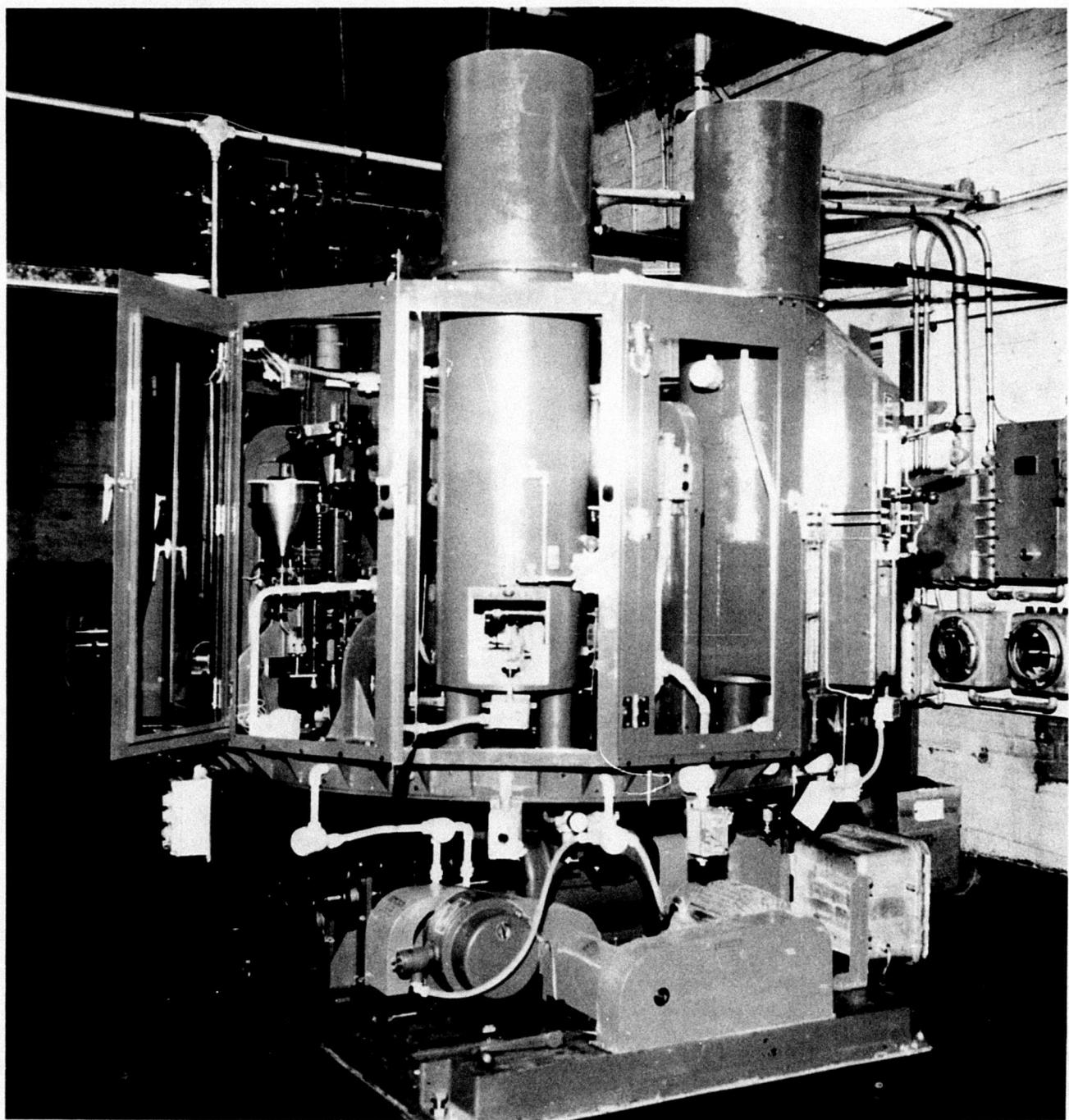


Figure 3. Iowa loader

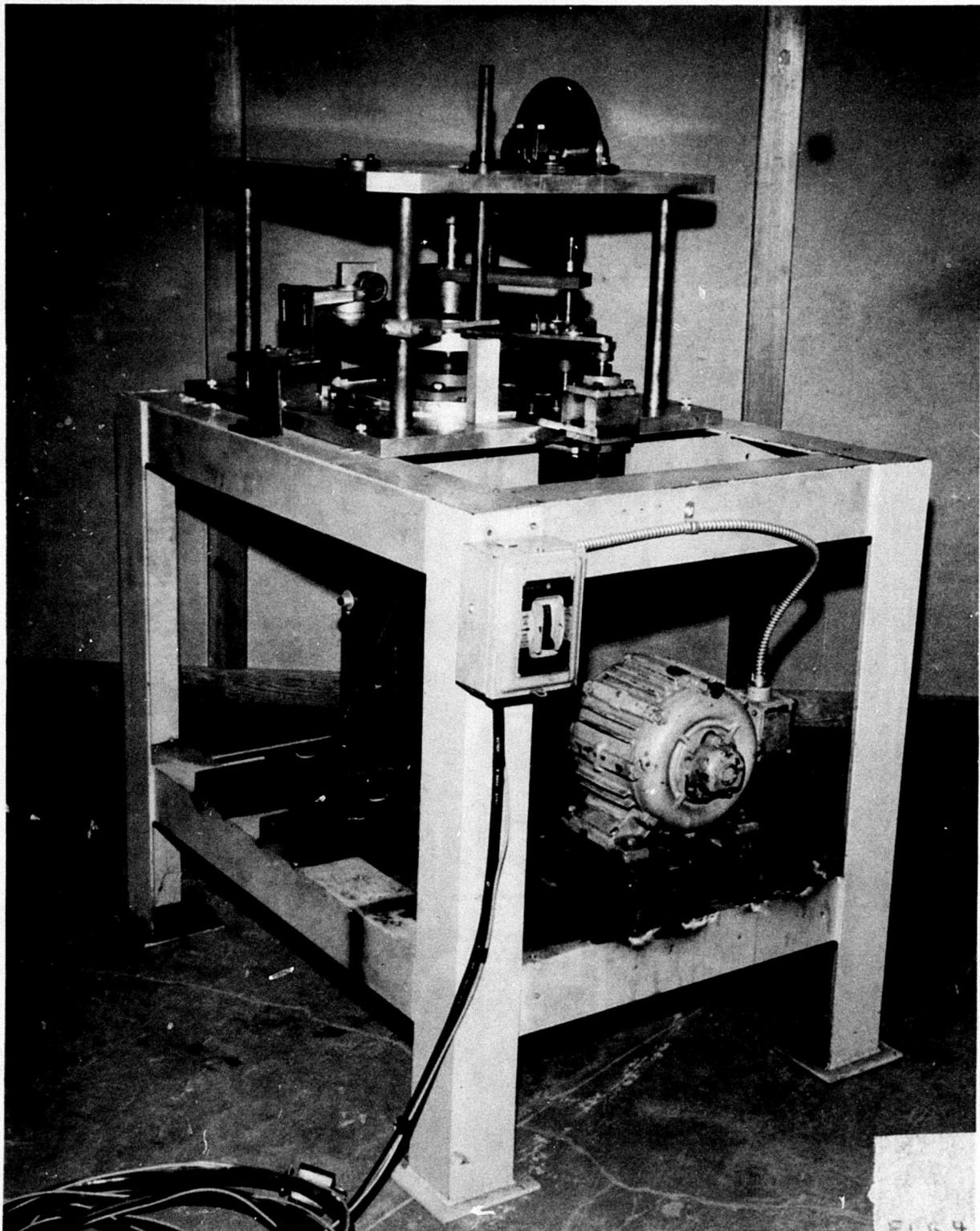


Figure 4. Experimental bench model, rotary compaction press

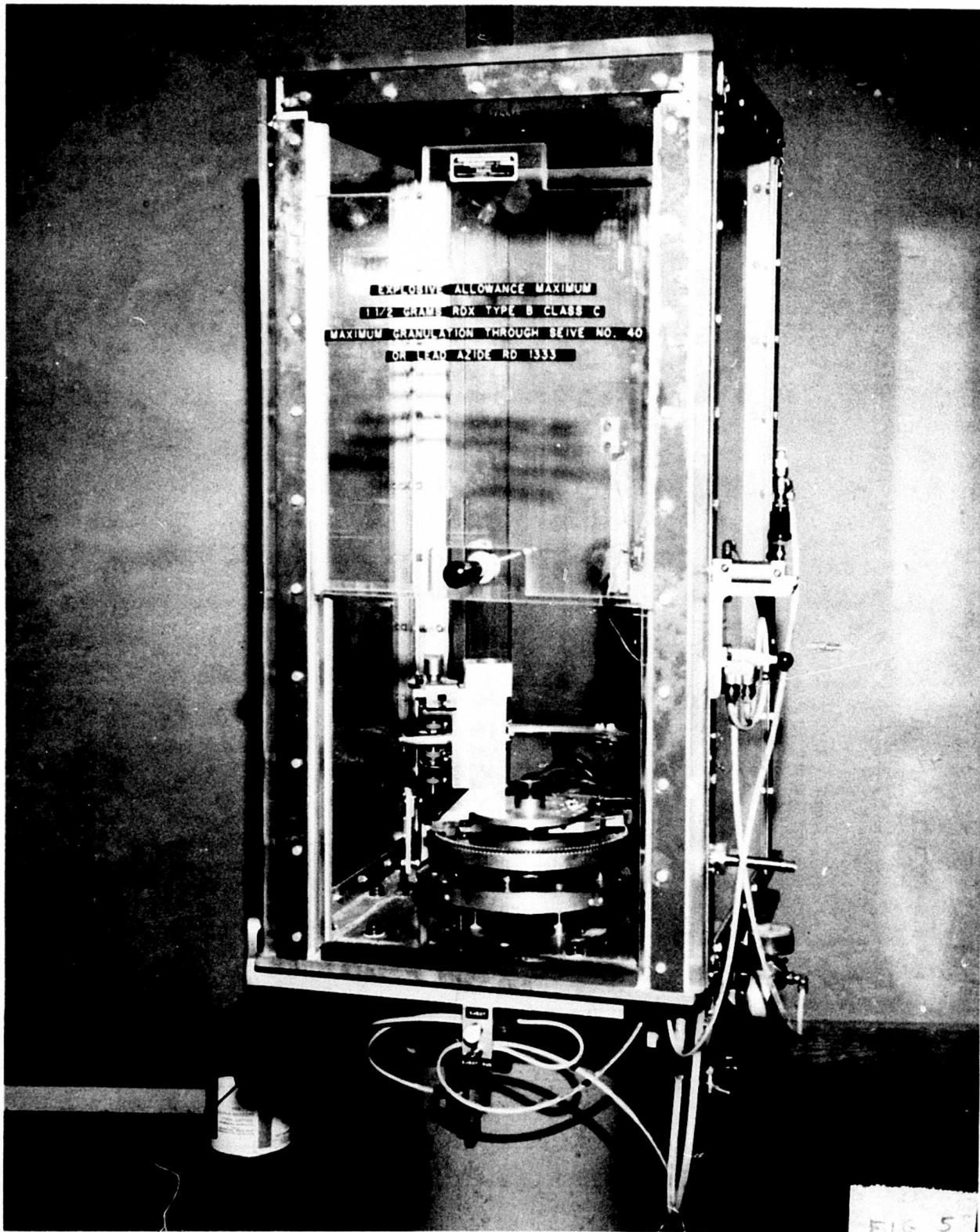


Figure 5. Experimental centrifugal dispenser

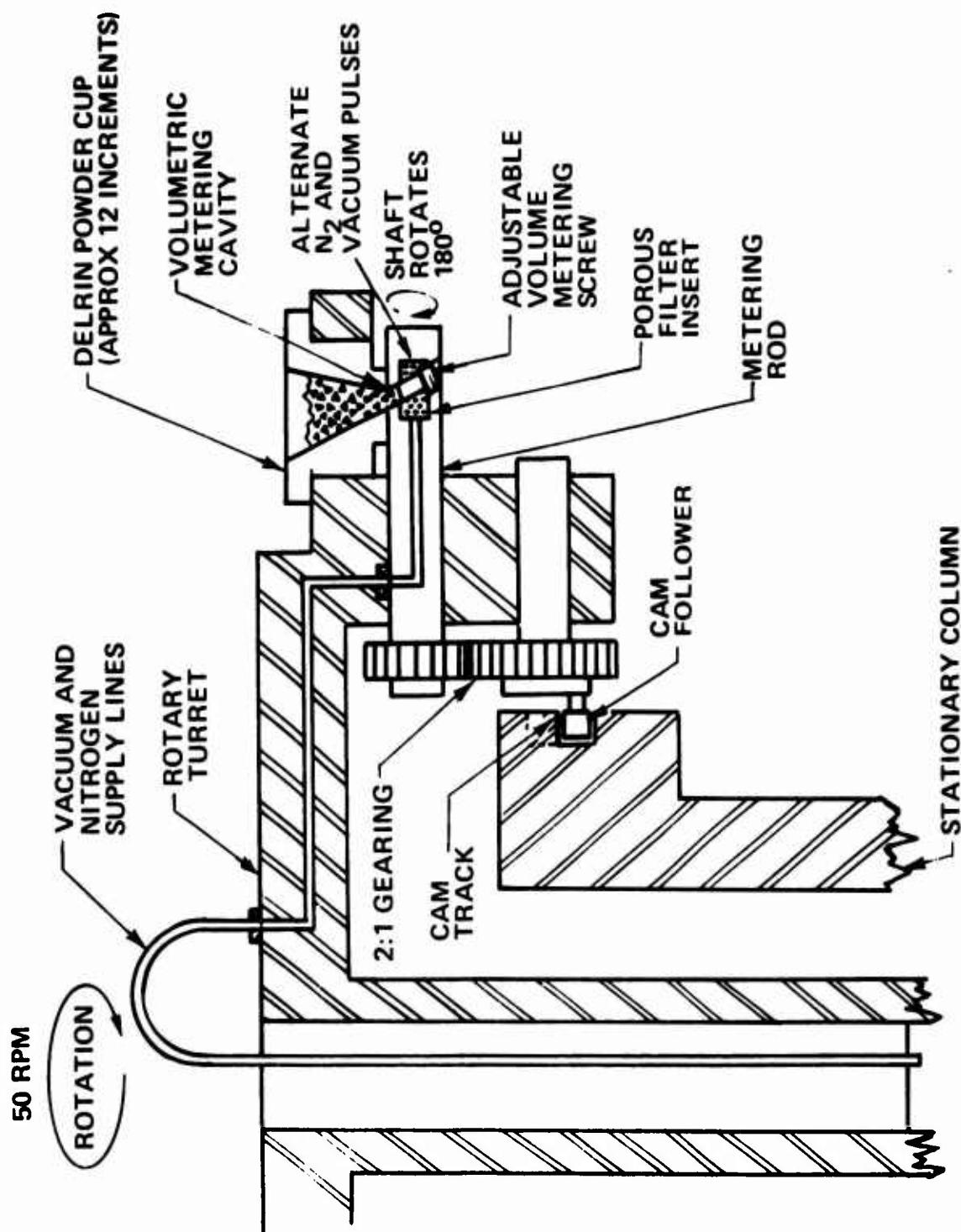


Figure 6. Metering concept

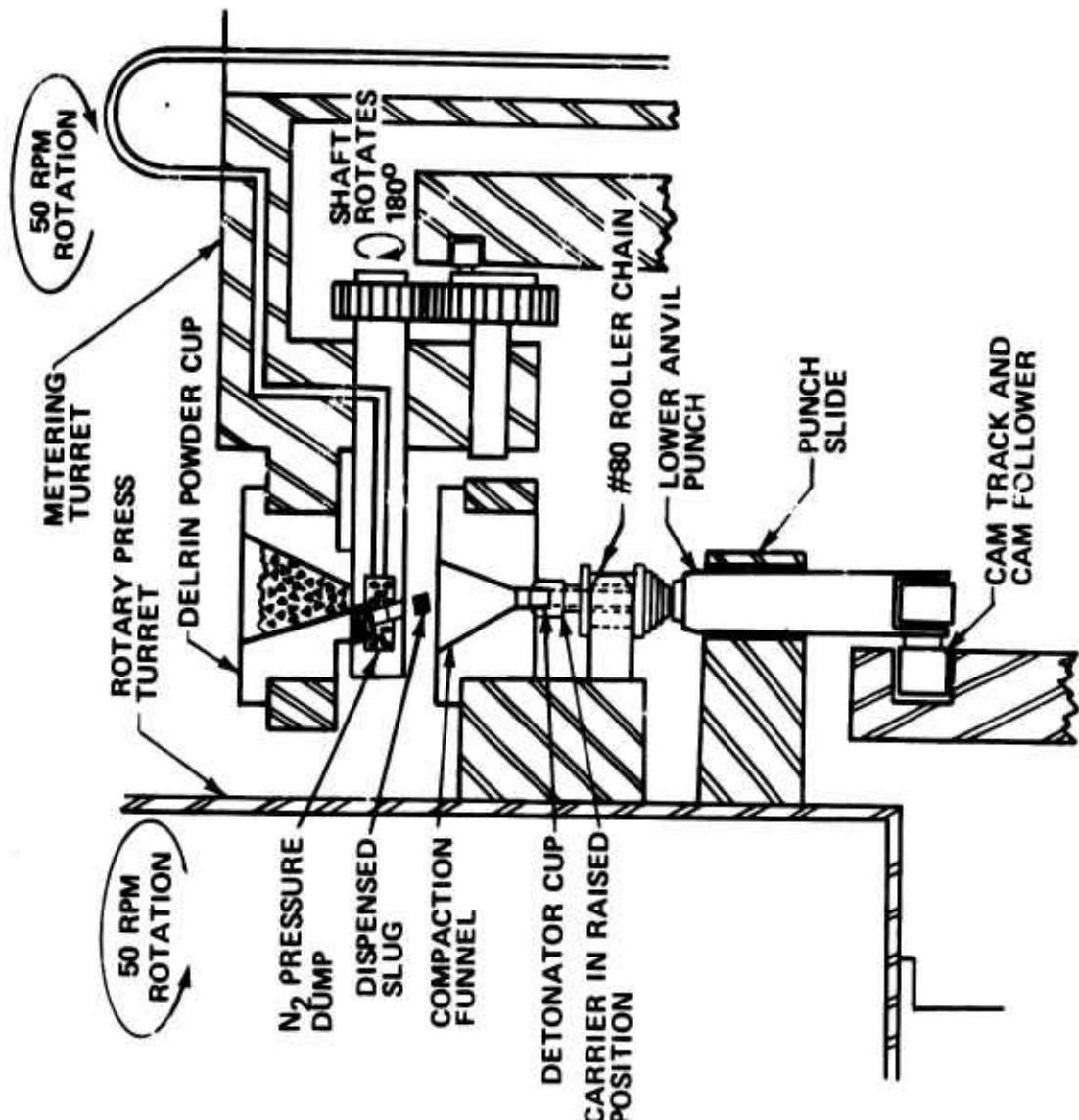


Figure 7. Dispensing concept

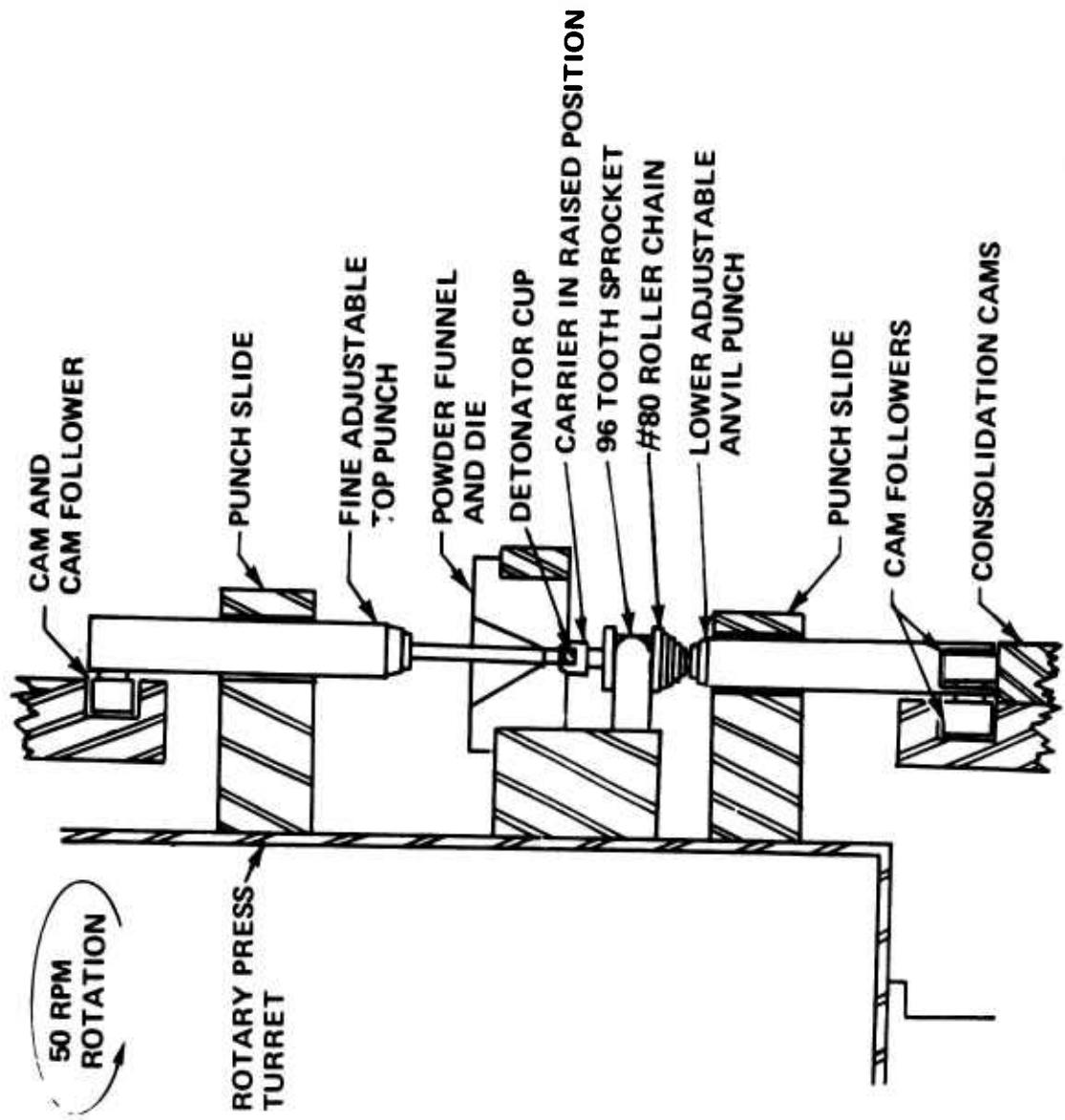


Figure 8. Consolidation concept

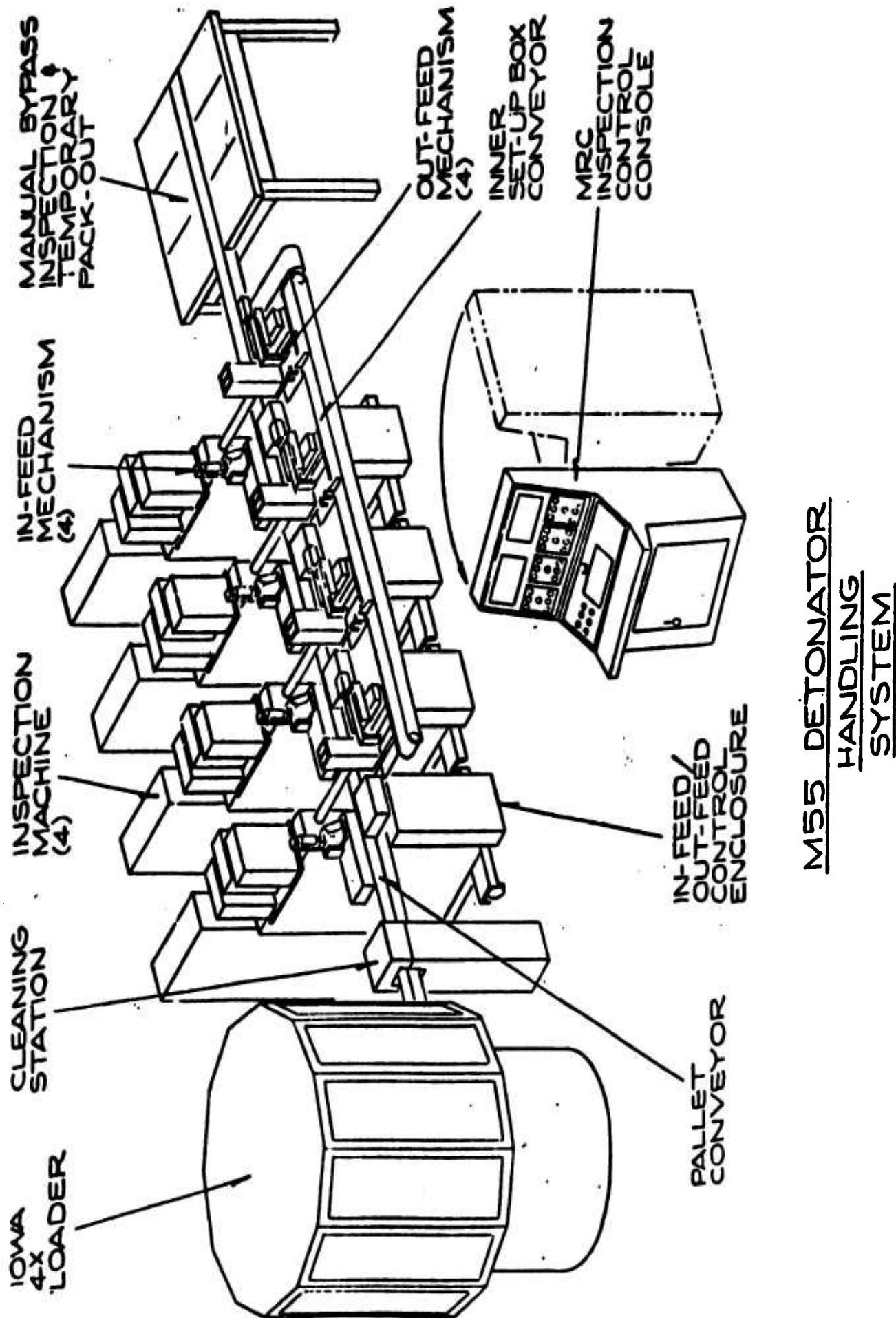


Figure 9. M55 detonator handling system

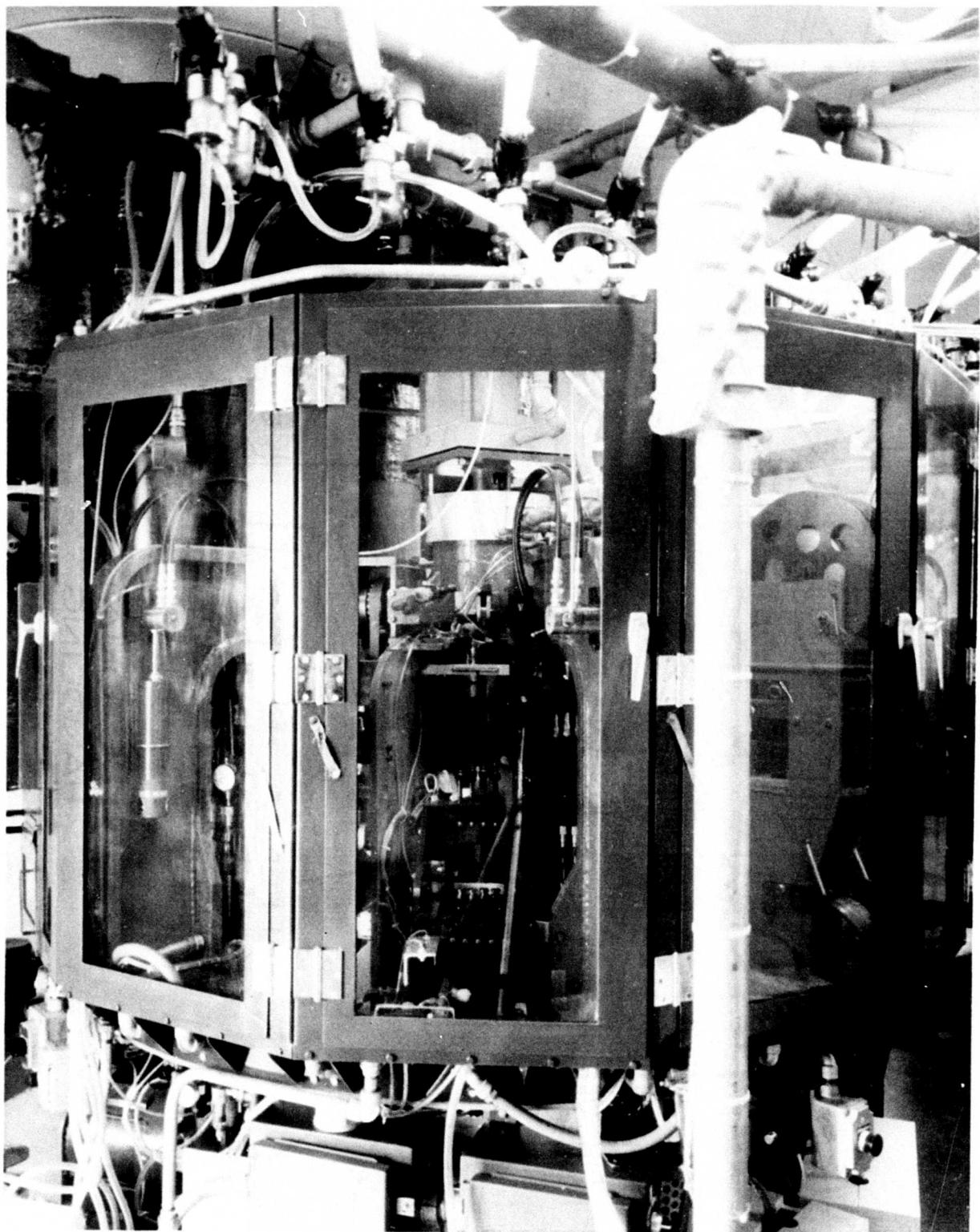


Figure 10. X-4 loader with shielding, pellet feed area

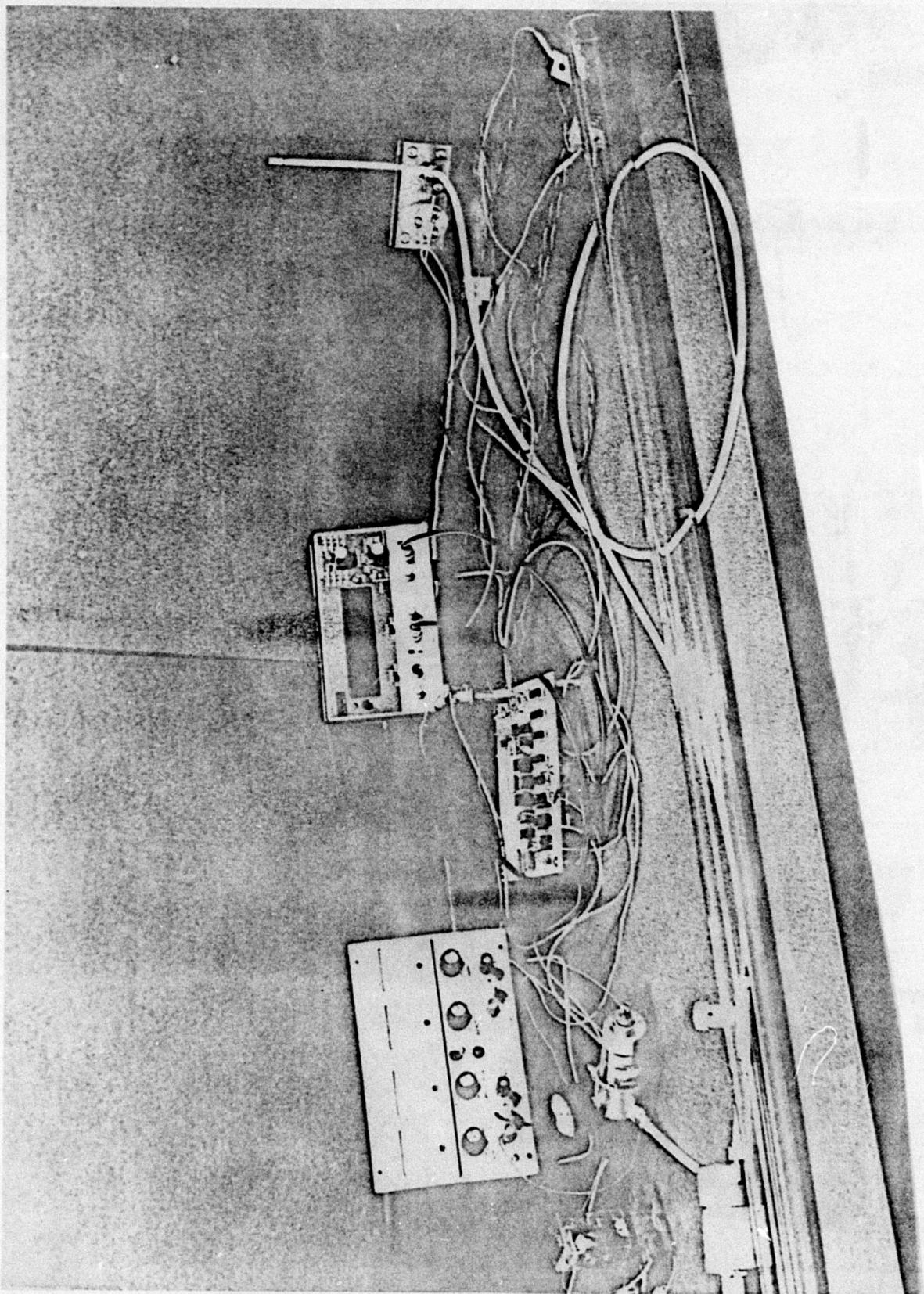


Figure 11. Propagation test setup

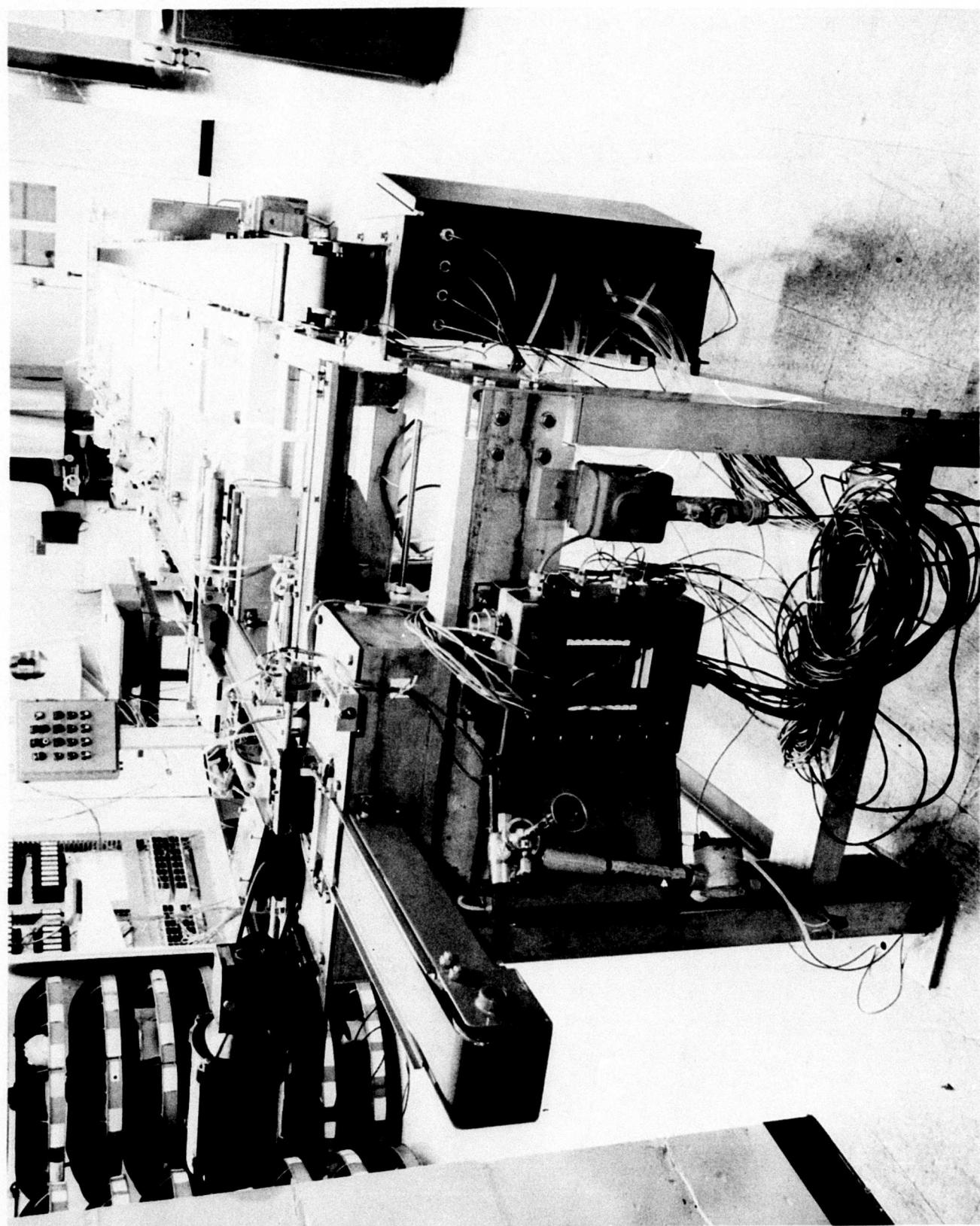


Figure 12. Material handling system view from cleaning station end

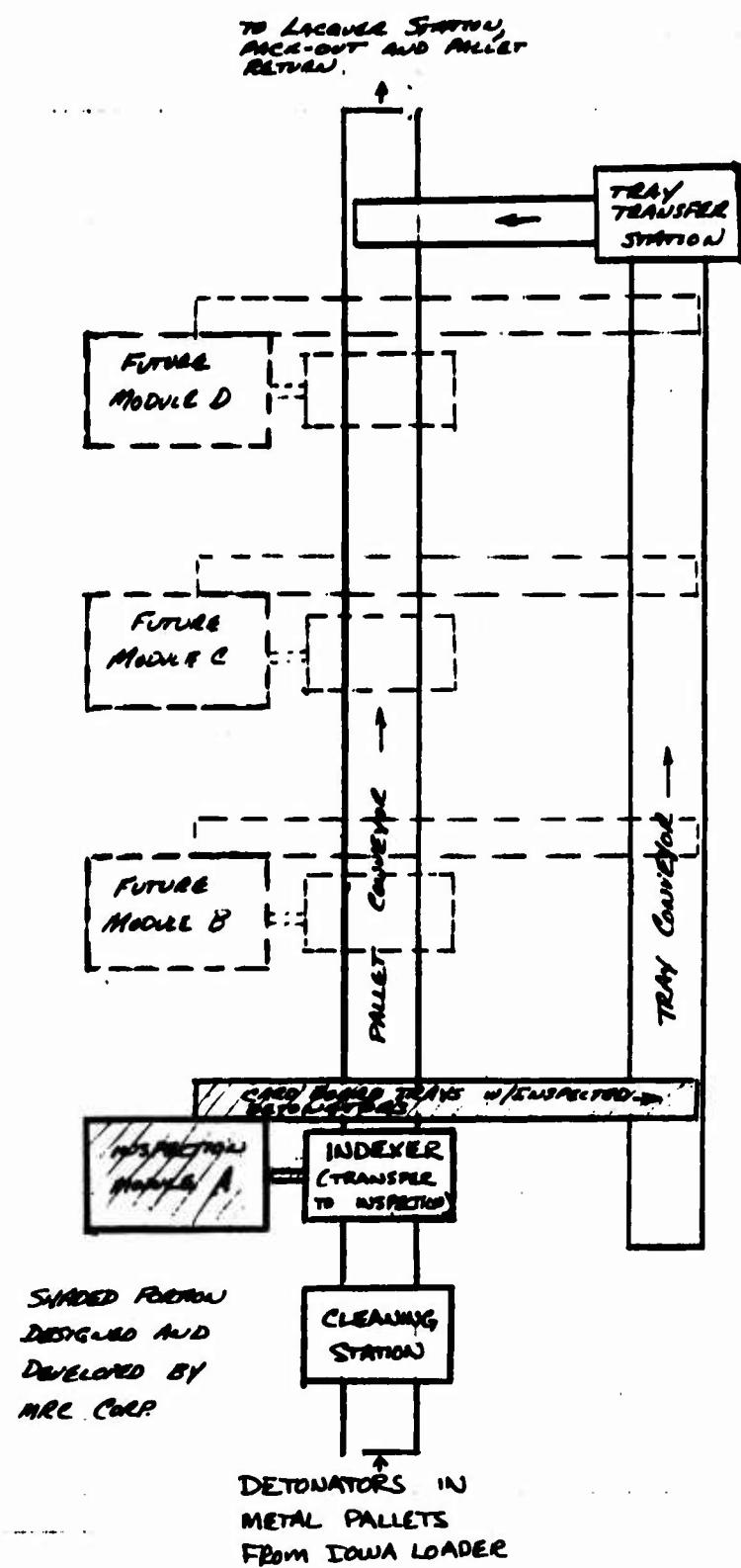


Figure 13. Prototype material handling system layout

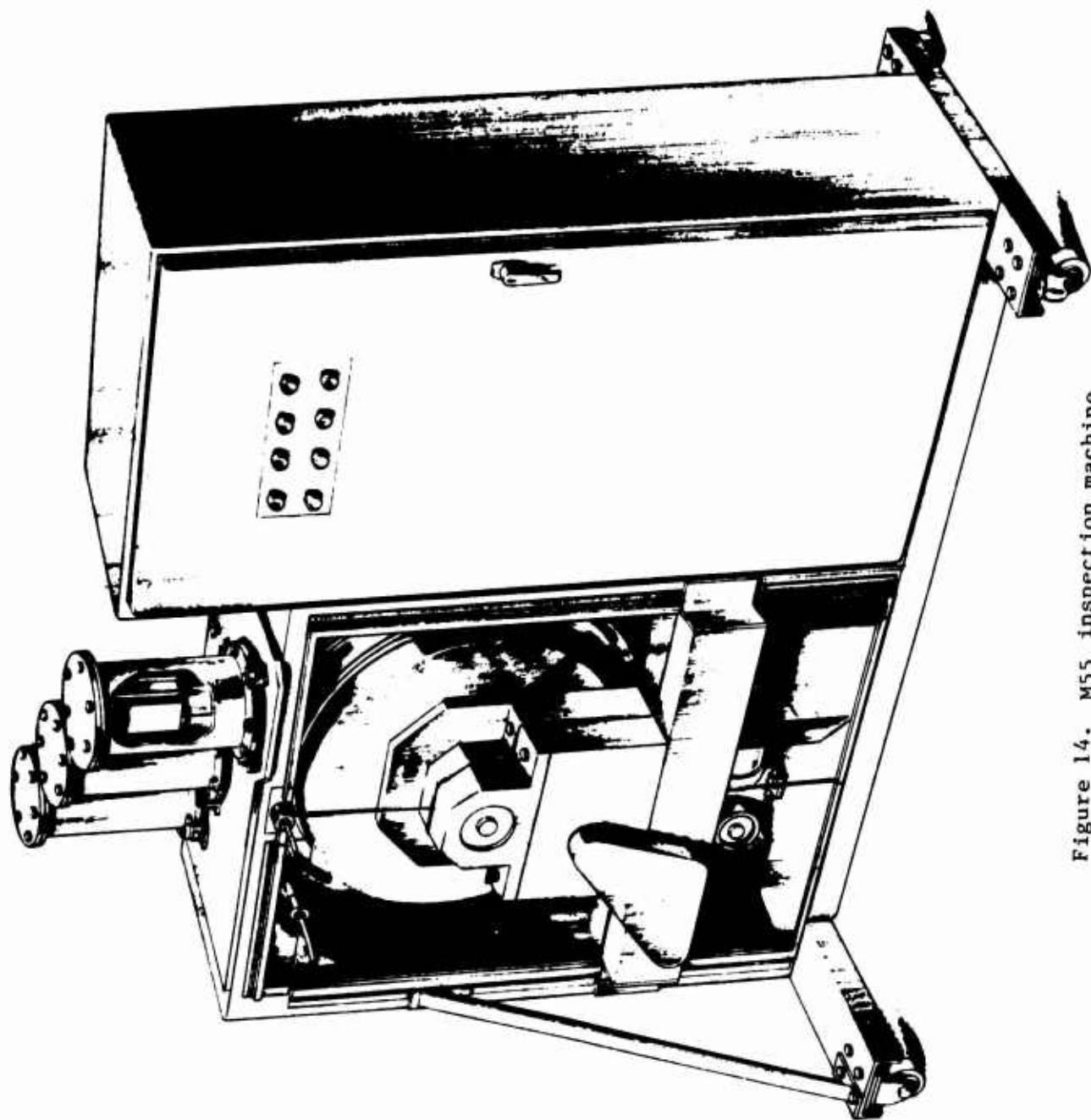


Figure 14. M55 inspection machine

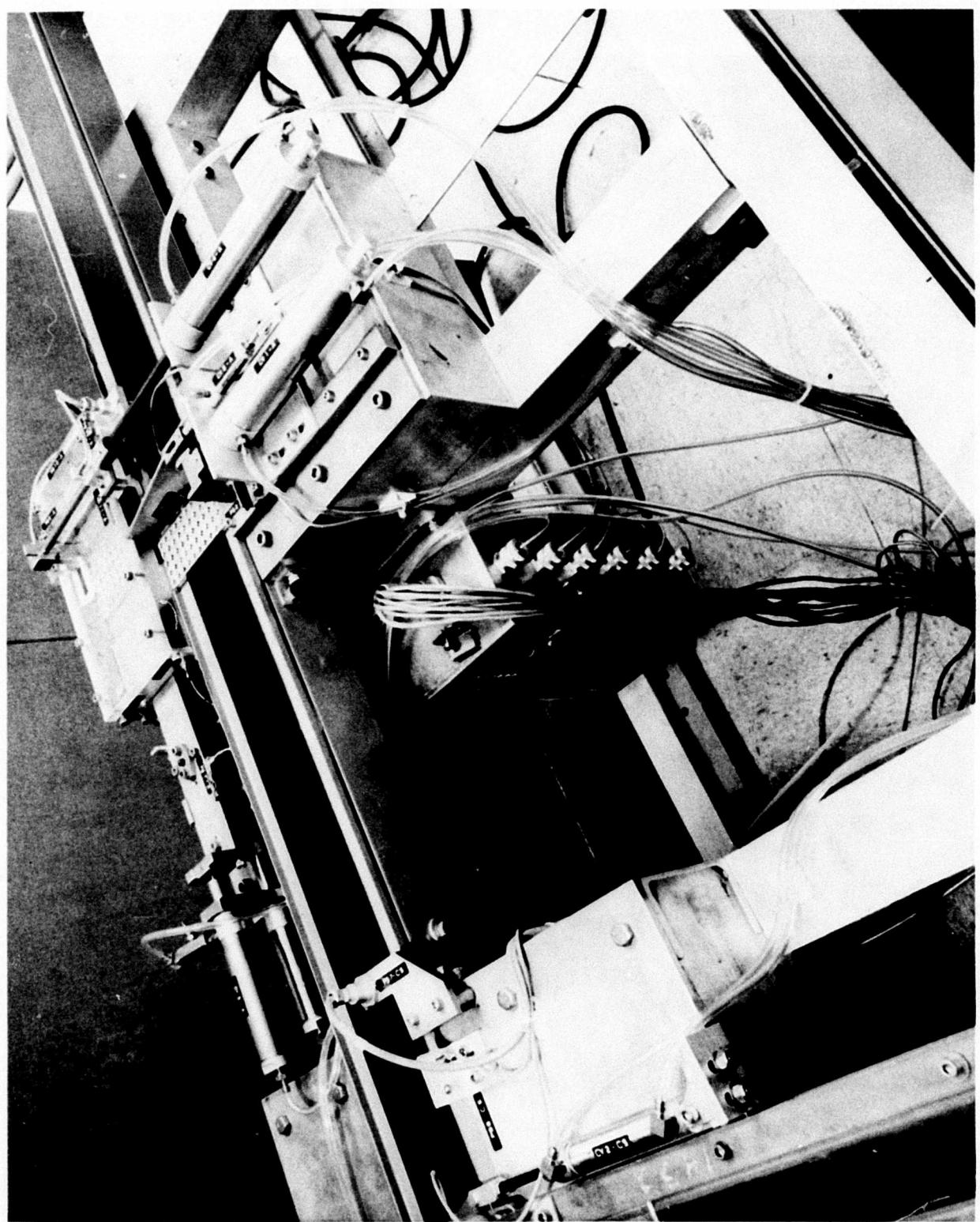


Figure 15. Material handling system indexer

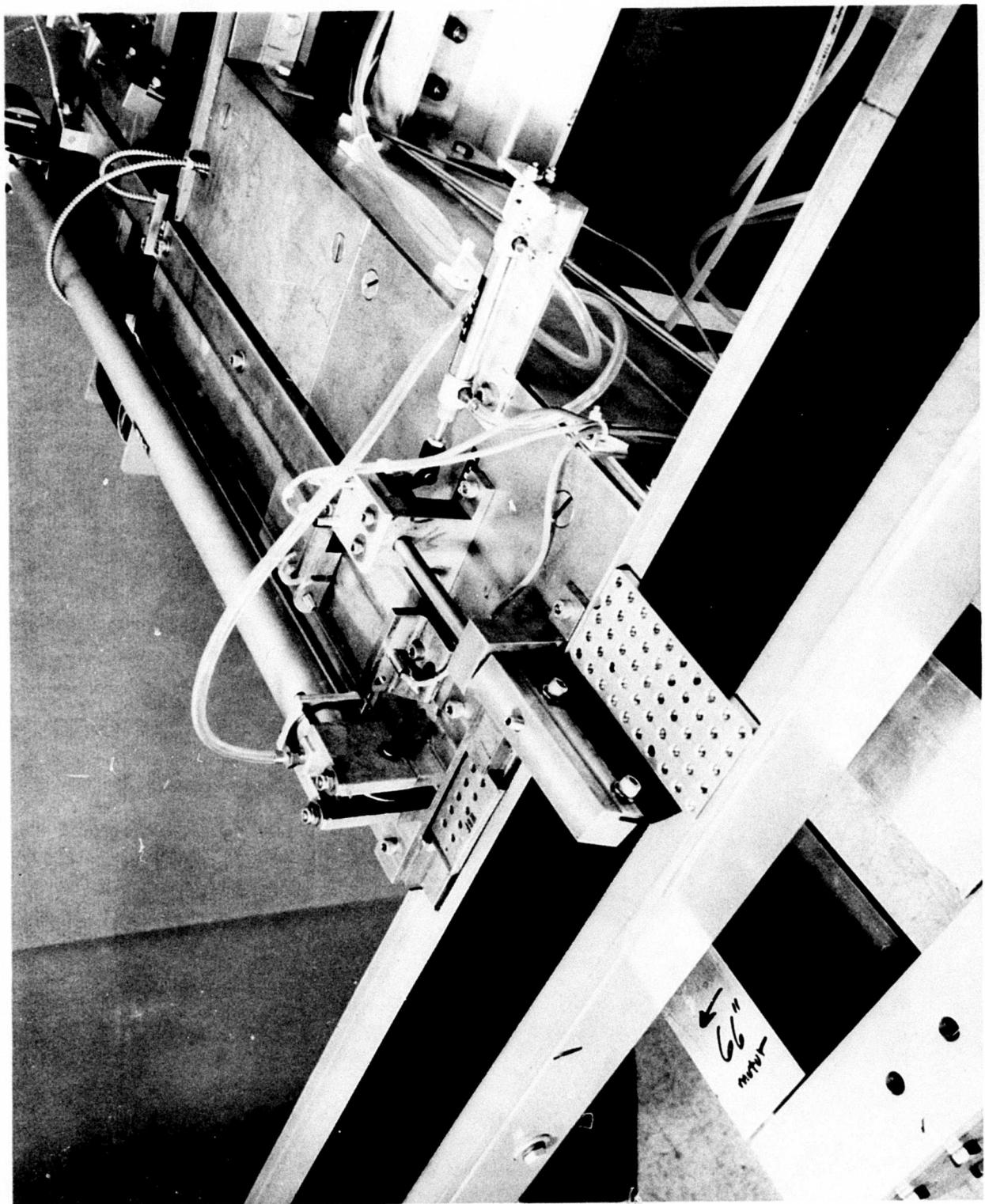


Figure 16. Tray transfer of material handling system

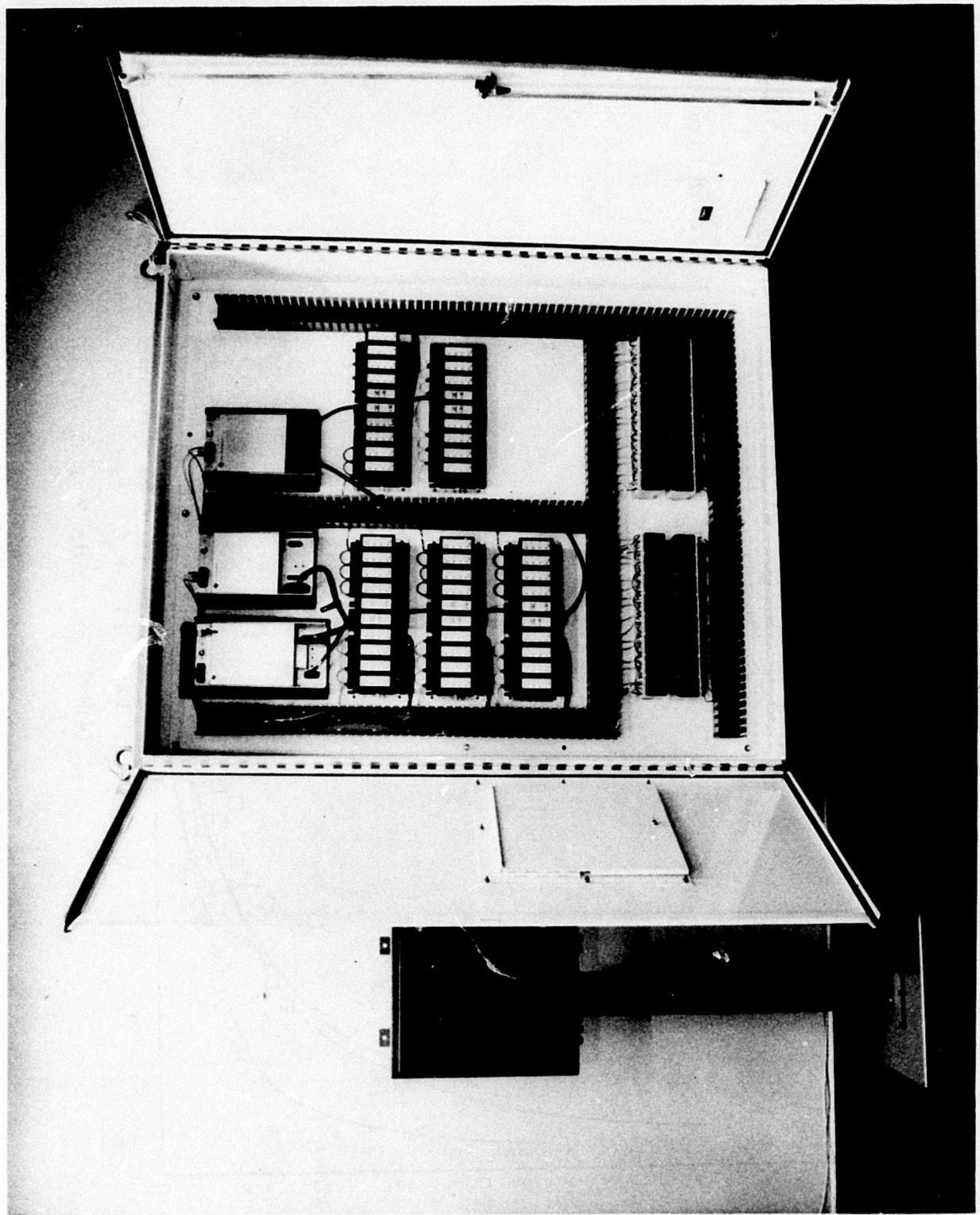


Figure 17. Control system PLC and manual control panel material handling system

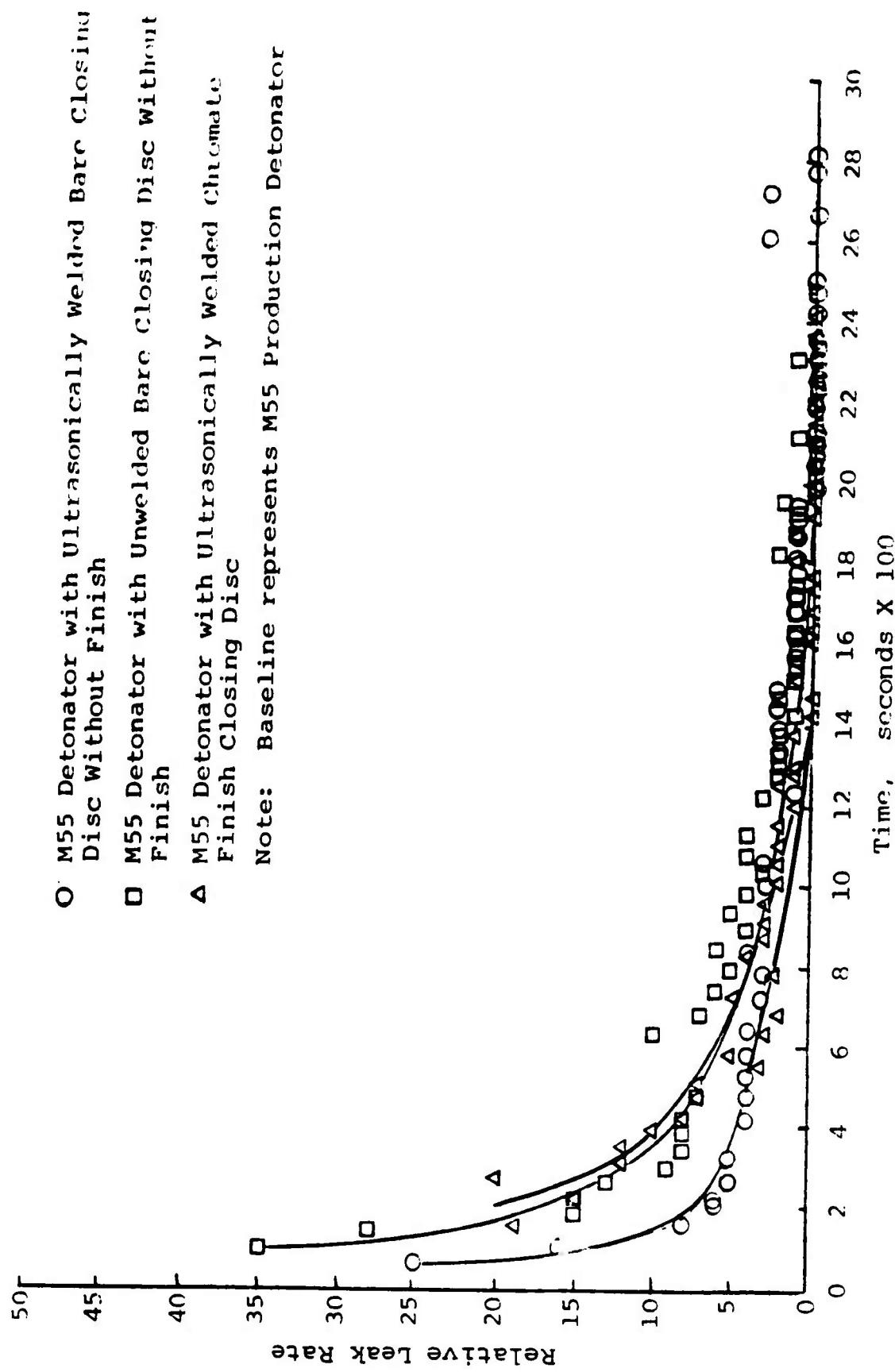


Figure 18. Relative leak rates for detonators

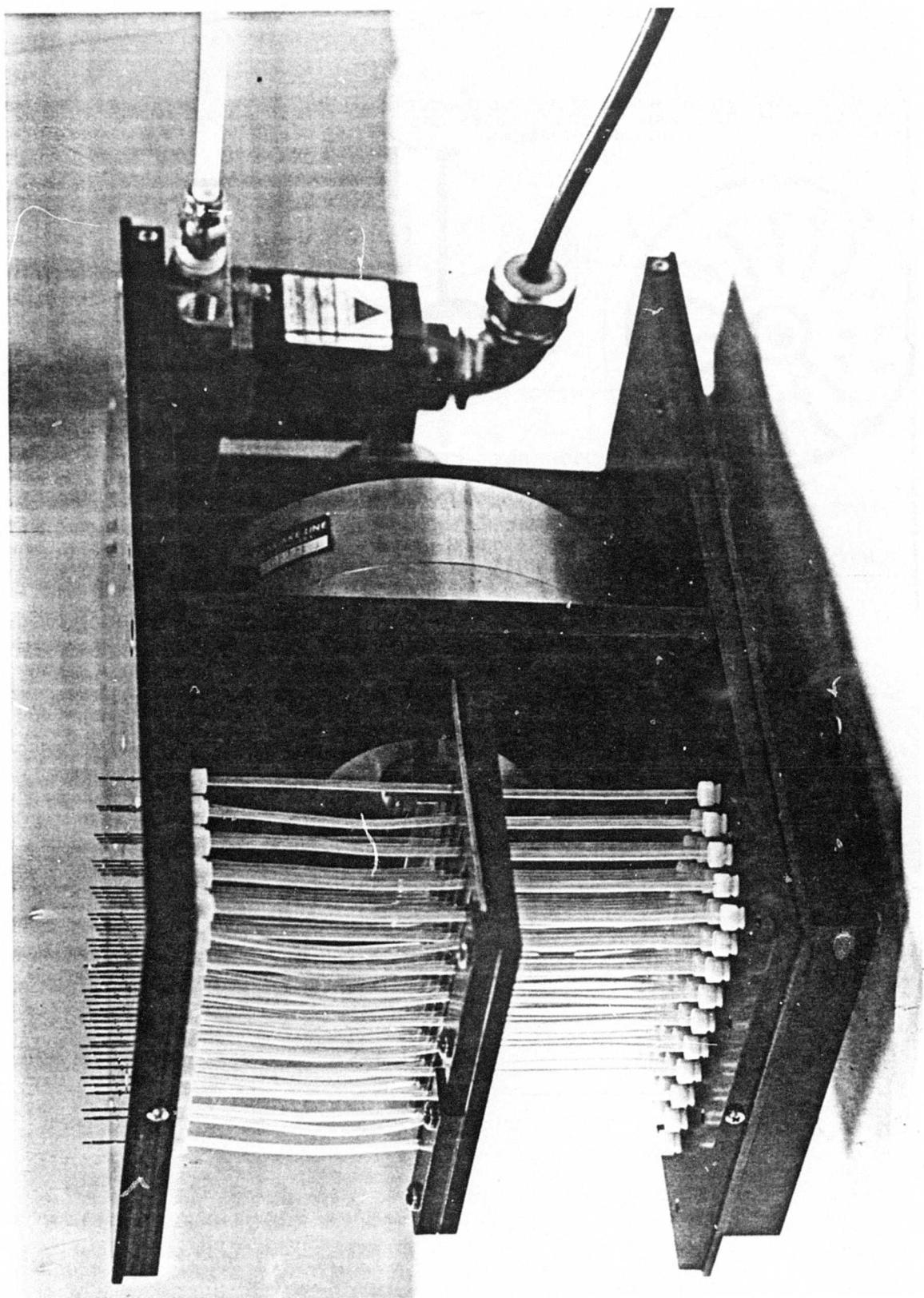
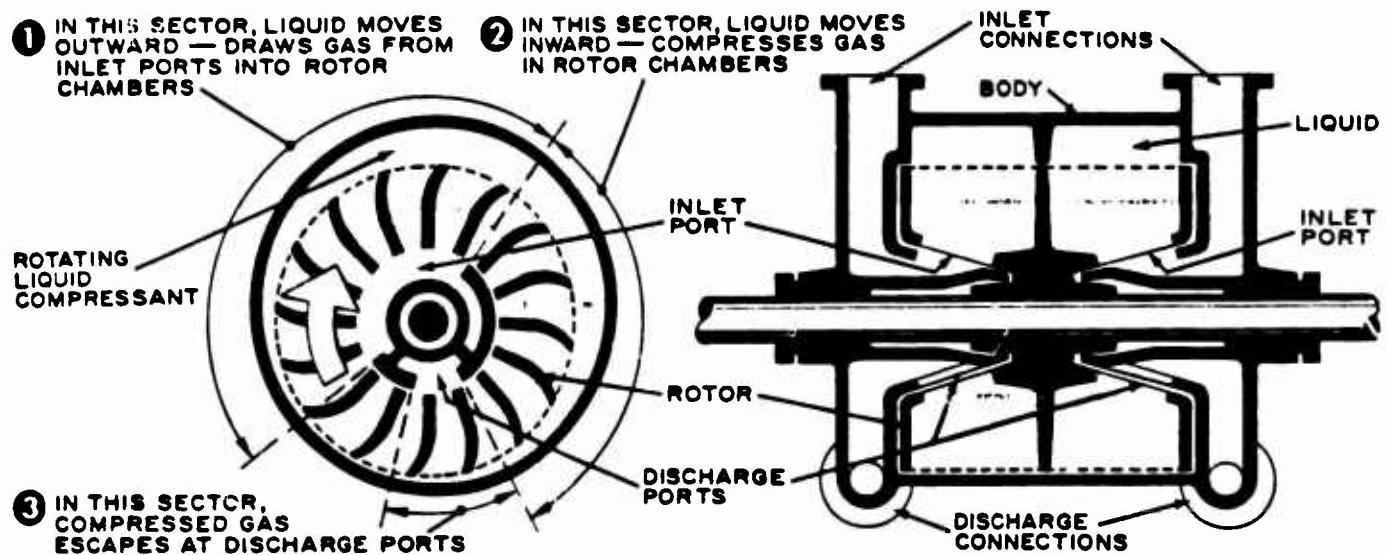


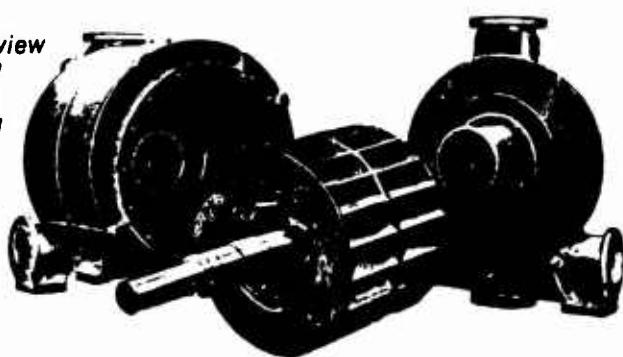
Figure 19. Lacquer dispenser with shroud removed



Functional schematic of Nash unit.

HOW IT WORKS

Disassembled view shows physical appearance of rotor, body and ported cones indicated on schematic.



The Nash compressor or vacuum pump has only one moving part — a balanced rotor that runs without any metal-to-metal rubbing contact. Such simplicity is possible because all functions of mechanical pistons or vanes are actually performed by a rotating band of liquid compressant. While power to keep it rotating is transmitted by the rotor, this ring of liquid tends to center itself in the cylindrical body. Rotor axis is offset from body axis. As the schematic diagram shows, liquid compressant almost fills, then partly empties each rotor chamber during a single revolution. That sets up the piston action. Stationary cones inside the rotor blades have ported openings that separate gas inlet and discharge flows.

Figure 20. Vacuum pump

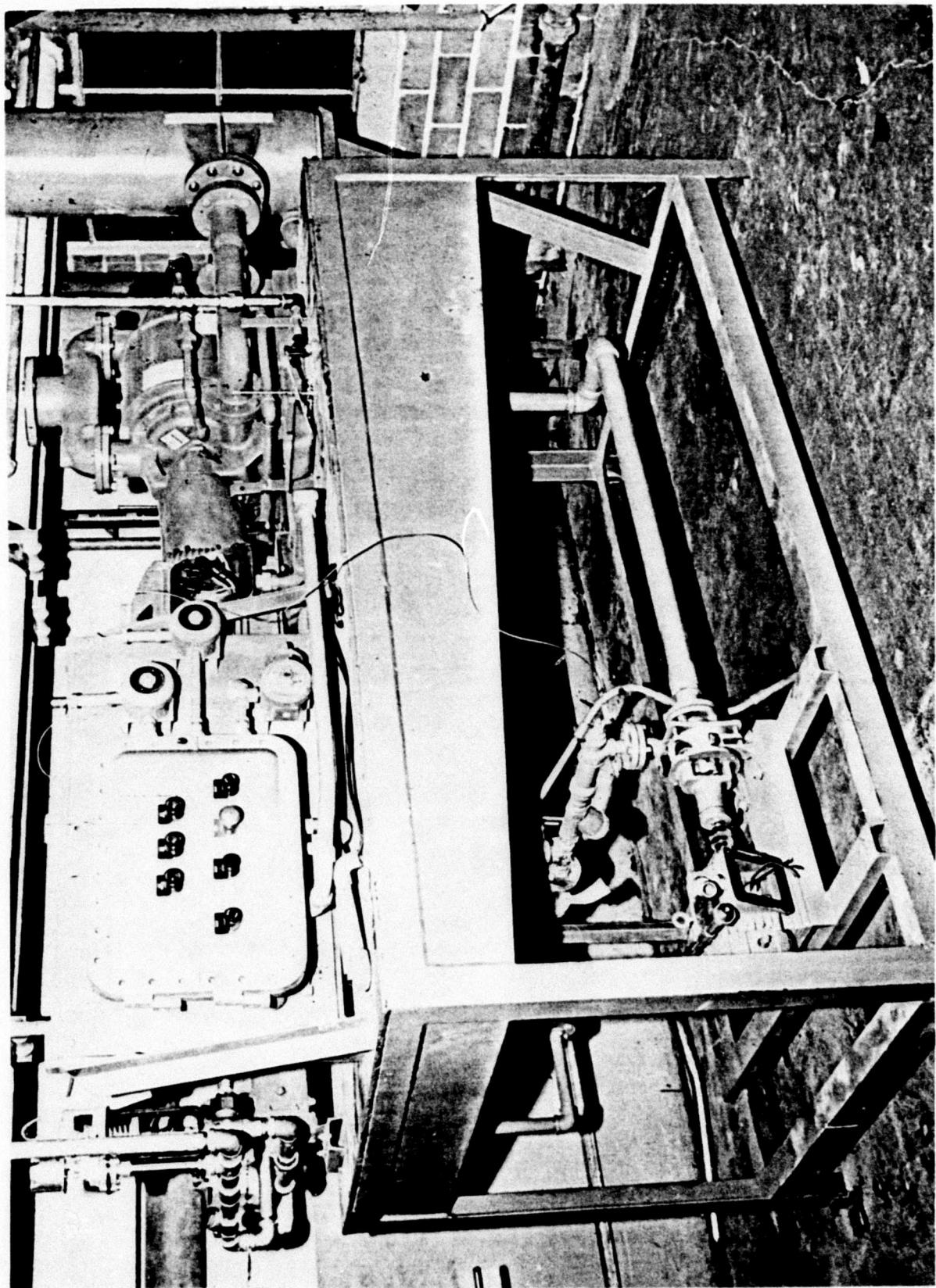


Figure 21. Pre-installation view of liquid ring vacuum pump

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